TREATMENT OF LANDFILL LEACHATE USING UV-HYDROGEN PEROXIDE SYSTEM IN BATCH PROCESS

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

AP. Dr. Mohamed Hasnain Isa
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
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December 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Rozaini Binti Ismail

ABSTRACT

UV-Hydrogen Peroxide (UVHP) system is one of the alternative methods for the treatment of landfill leachate. This study focuses on the effectiveness of UVHP system for the treatment of Pulau Burung Landfill Site (PBLS) leachate by examining the effect of operating parameters to the treatment efficiency.

Experimental design for UV-Hydrogen Peroxide treatment involves Three-Level Factorial design and the data is analysed using the Response Surface Methodology (RSM). The factors for the experiments are pH, reaction time and hydrogen peroxide concentration while the responses are removal of chemical oxygen demand (COD) and colour of the sample. Another response for this treatment is 5-day biological oxygen demand (BOD_5) purposely to check the biodegradability of the leachate by BOD/COD ratio.

The trend of colour removal and COD removal with respect to pH, reaction time and hydrogen peroxide concentration is to be been determined. From the results, it is shown that low level pH, high level hydrogen peroxide concentration and high level reaction time gives greater removal of colour and COD. Treatment at pH 2, hydrogen peroxide concentration of 5000 mg/L and reaction time at 90 minutes achieves maximum colour, 87.82%. Whereas, the maximum COD removal also occurs at the same treatment conditions which is 50.66%. The BOD of leachate also has been improved to comply with the Environment Quality Act (EQA) Standard after UVHP treatment. The maximum removal of BOD is 80.3%, reduced from 317 mg/L to 62.44 mg/L. UVHP treatment is an effective alternatives method for removal of colour, COD and BOD of PBLS leachate.

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INTRODUCTION

1.1 Background of Study

In Malaysia and other developing countries, landfill is commonly used to dispose solid waste. Improper disposal of Municipal Solid Waste (MSW) into landfills not only creates a favourable environment for pests like rats, flies and others but also pollutes the ecosystem with the release of leachate. Due the infiltration of rainwater and microbial degradation of organic matter in the landfill, leachate is produced. The production of leachate is not as much as compared to other wastewaters but it can cause severe adverse effect on the environment if not treated properly. Leachate which contains extremely hazardous materials can migrate from the landfill and cause pollution of soils, ground water and surface water (Akesson and Nilsson, 1997; El-Fadel et al., 2002; Silva et al., 2004; Tizaoui et al., 2007). Shown in Figure 1.1 is the leachate flowing on the ground in the landfill. This leachate possibly will penetrate into the ground and moves from the landfill to other places and cause adverse impact to the environment.

Figure 1.1: Leachate flowing on the lower ground

1.2 Problem Statement

Pulau Burung Landfill Site (PBLS), Nibong Tebal, Pulau Pinang, Malaysia, covers a total of 23.7 ha and it is equipped with a leachate collection pond. Since it was designed as semi-aerobic, the level of organic contaminants in the leachate of this landfill is lower compared to anaerobic landfills (Yeong, 2007). The leachate from PBLS was found out to have a high BOD_5 values (377 mg/L) and even higher COD values (2860 mg/L). The low BOD_5/COD ratio (0.17) and high ammoniacal nitrogen concentration (1225 mg/L) indicates that the leachate has low biodegradability and high degree of stabilisation (Aghamohammadi et al., 2007; Munter, 2001).

The biological treatment options of mature leachate become limited due to the existence of toxic contaminants and recalcitrant organics (Petruzzelli et al., 2005; Tizaoui et al., 2007). Therefore the purpose of the study is to reduce the value of COD and BOD_5 in order to improve the biodegradability of the leachate by treating the leachate using UV-Hydrogen Peroxide System.

1.3 Research Objectives

The present research has the following objectives:

a) To assess the effectiveness of UVHP system by determining the percentage reduction of colour, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5) and evaluating the BOD_5/COD of the treated leachate.

b) To determine the effect of process parameters (pH, hydrogen peroxide concentration and reaction time) on the treatment of PBLS leachate

c) To develop a model of UV/Hydrogen Peroxide (UVHP) system for the treatment of PBLS leachate

1.4 Scope of Study

Leachate characterisation is included in the scope of study. The characterisation test includes the measurement of total chemical oxygen demand, soluble chemical oxygen demand, biological oxygen demand, total suspended solid, total kjeldahl nitrogen, turbidity, colour, total phosphorus, ammonia nitrogen and sulphate.

Preliminary experiment was done in order to determine the effect of pH adjustment to the leachate. The effect is determined based on colour and chemical oxygen demand conversion.

For the treatment using UVHP system, Response Surface Methodology (RSM) is used to design the experiment as to determine the effect of pH, hydrogen peroxide concentration and reaction time to leachate treatment. BOD of treated leachate is measured in order to determine the biodegradability of the leachate.

CHAPTER 2

LITERATURE REVIEW

2.1 Leachate

Leachate is the liquid that has infiltrated through solid wastes and has extracted dissolved and suspended materials. Pollution of groundwater, surface water and soil are the major potential environmental impacts related to landfill leachate. The risk of groundwater pollution is probably the most severe environmental impact from landfills since formerly most landfills were built without engineered liners and leachate collection systems. More recently, regulation in many countries have demanded the installation of liners and leachate collection systems as well as a plan for leachate treatment (Kjeldesen et al., 2002; Tizaoui et al., 2007).

Currently in Malaysia, 145 local authorities are implementing Solid Waste Management (SWM) as provided under the Local Government Act 1976, Street Drainage & Building Act 1974 & Public Cleansing & Safety (Penang Island Municipal Council) By-Laws 1980. Over the years, there have been increments in daily waste generation. As an example, waste deposited at Pulau Burung Landfill Site (PLBS), Penang increased from 547 metric ton per day in 2001 to 808 metric ton per day in 2006 (Yeong, 2007). The increment of waste generation indirectly indicated the increment of leachate production.

Semi-aerobic leachate is characterized by organic matter (COD, BOD) which is relatively low in concentration and difficult to biodegrade. In conventional treatment systems, the low biodegradability is attributed to partial stabilization of leachate at the landfill. The behaviour of microbes is unknown for semi aerobic leachate. Biological process are effective for young leachate treatment, but less so for stabilised leachate. Application of conventional biological treatment to landfill leachate is usually limited by the presence of toxic contaminants and recalcitrant organics (Aghamohammadi et al., 2007; Petruzzelli et al., 2005; Tizaoui et al., 2007).

2.2 Advanced Oxidation Process (AOP)

As biological treatment alone is not able to treat stabilised leachate, Advance Oxidation Process (AOP) is proposed as the pre-treatment. AOPs apply different reacting systems but are all characterised by the production of $OH^{\bullet}$ radicals. AOPs are suited for destroying dissolved organic contaminants, aromatic compounds, detergents, etc and also oxidise inorganic contaminants such as cyanide, sulphide and nitrite. Advance oxidation methods can be categorised into two which are non-photochemical and photochemical (Bolton et al., 1996; Metcalf and Eddy, 2004; Munter, 2001; Petruzzelli et al., 2005). Table 2.1 shows the relative oxidation power of oxidising species.

Table 2.1: Relative Oxidation Power of Some Oxidising Species

Oxidising agent/species	Relative oxidation power	Electrochemical oxidation potential (EOP), V
Positively charged hole on titanium dioxide, TiO_2	2.35	-
Fluorine	-	3.06
Hydroxyl radical	2.05	2.80
Atomic oxygen	1.78	2.42
Ozone	1.52	2.08
Hydrogen peroxide	1.31	1.78
Chlorine	1.00	1.36

(Carey, 1992; Metcalf and Eddy, 2004; TECHCOMMENTARY, 1996)

The hydroxyl radical which is a powerful and strong oxidant can react very rapidly with most of organic compounds (Munter, 2001; Mahmoudet al., 2007). When the hydroxyl radical is generated, it aggressively attacks almost all organic compounds without limitation to specific classes or groups of compounds as compared to other oxidants. The hydroxyl radical reacts with the dissolved constituents, initiating a series of oxidation reaction until the constituents are completely mineralised. The hydroxyl radical is also non selective in its mode of attack and able to operate at normal temperature and pressure (Metcalf and Eddy, 2004). The choice of process to generate the hydroxyl radicals depends on the nature

of the water and pollutants to be treated. Listed below are a few different ways to generate the $OH^{\bullet}$ radicals (Munter, 2001).

i. Fenton Reagents (H_2O_2 /Fe^{2+})
ii. Photo-Fenton (H_2O_2 /Fe^{2+} and UV light)
iii. H_2O_2 / UV light
iv. O_3/ H_2O_2 /Fe^{2+}
v. Modified Photo Fenton (UV-vis/Ferrioxalate/ H_2O_2)

As for this project, combination of UV radiation and hydrogen peroxide is chosen for the pre-treatment of leachate. Both hydrogen peroxide and UV can be used alone to facilitate the degradation of certain contaminants. Hydrogen peroxide is a very strong oxidizing agent, capable of destroying some halogenated compounds and most non-halogenated compounds in aqueous media. UV light itself is also very capable of degradation by initiating bond cleavage. However, the range of contaminants UV can degrade by itself is limited. The rate of degradation can also be very slow (Melanie et al., 1998).

Based on numerous studies, it has been found that combined AOPs are more effective than any of the individual agents (e.g., ozone, UV, hydrogen peroxide). The combination of the two treatments, hydrogen peroxide and UV can create a very fast and efficient process for remediation. From this process, recalcitrant/toxic compounds can be broken down and the biodegradability of leachate can be improved. The direct photolysis of hydrogen peroxide leads to the formation of $OH^{\bullet}$ radicals (Carey, 1992; Metcalf and Eddy, 2004; Mahmoud et al., 2007; TECHCOMMENTARY, 1996; Sari and Mika, 2009).

In reaction (1), the ultraviolet (UV) light causes dissociation of H_2O_2 into two hydroxyl radicals.

$$H_2O_2 \xrightarrow{uv} 2OH^{\bullet} \qquad (1)$$

Hydroxyl radical can attack organic molecules in the following ways:

Radical addition

The addition of the hydroxyl radical to an unsaturated aliphatic or aromatic organic compound results in the production of a radical organic compound that can be oxidised further by compounds such as oxygen to produce stable oxidised end products.

$$R + OH^{\bullet} \longrightarrow ROH \qquad (2)$$

Hydrogen abstraction

The removal of a hydrogen atom results in formation of a radical organic compound, initiate a chain reaction where the radical organic compound reacts with oxygen, producing a peroxyl radical.

$$R + OH^{\bullet} \longrightarrow R^{\bullet} + H_2O \qquad (3)$$

Electron transfer

Electron transfer results in the formation of ions of a higher valence. Oxidation of a monovalent negative ion will result in the formation of an atom or a free radical.

$$R^{n} + OH^{\bullet} \longrightarrow R^{n-1} + OH^{-} \qquad (4)$$

Radical combination

Excess production of hydroxyl radical may reduce the efficacy of the treatment as the hydroxyl radical tends to react with each other and combined to form a stable product.

$$OH^{\bullet} + OH^{\bullet} \longrightarrow H_2O_2 \qquad (5)$$

(Sari and Mika, 2009, Metcalf and Eddy, 2004)

2.3 Ultraviolet (UV) Radiation

Ultraviolet (UV) radiation occurs between 100 and 400 nm as the portion of electromagnetic spectrum. This range is characterised further according to wavelength as long-wave (UV-A), middle-wave (UV-B) and short-wave (UV-C) like shown in Figure 2.1. In general, UV system fall into three categories based on the internal operating parameters of the UV lamp, low pressure low intensity, low-pressure high-intensity, and medium–pressure high–intensity systems. In most commercial applications of UV/Hydrogen peroxide, low-pressure mercury vapour UV lamps are used to produce UV radiation (Metcalf and Eddy, 2004). The maximum absorbance of UV radiation by hydrogen peroxide occurs at about 220 nanometres (nm). However, the dominant emission wavelength of low-pressure mercury vapour UV lamps is at about 254nm (Munter, 2001). Shown in Figure 2.2 is the UV-Germicidal Lamp that is used in the experiment.

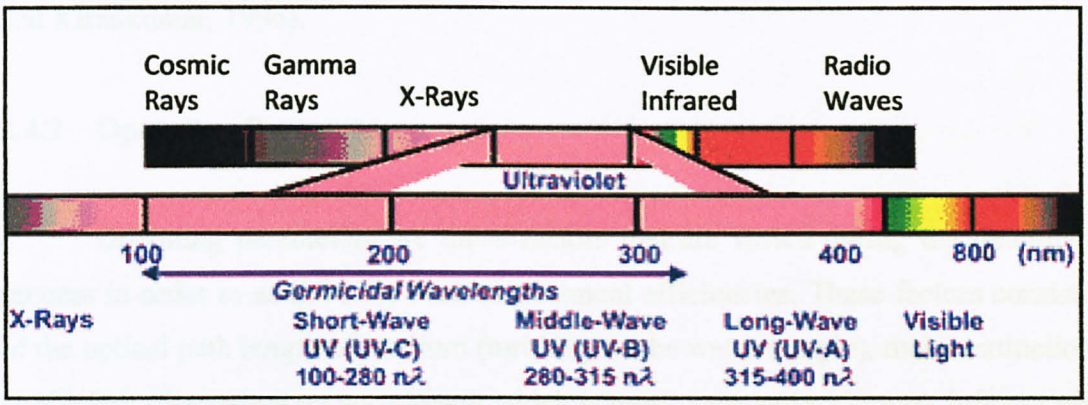

Figure 2.1: Ultraviolet Portion of the Electromagnetic Spectrum

Figure 2.2: UV Germicidal Lamp

2.4 Factors Influencing the Performance of UV/Hydrogen Peroxide System

Factors influencing the performance of UV/Hydrogen Peroxide system can be grouped into two categories: (1) wastewater characteristics, and (2) operating parameters.

2.4.1 Wastewater Characteristics

The types of contaminants to be treated influence the removal efficiency of the UV/Hydrogen Peroxide oxidation process. Organics with double bonds, vinyl chloride, and aromatic compounds are easily removed because they are readily oxidised. However, organics without double bonds and with low Henry's law constants are difficult to remove as they are not easily oxidised or stripped. Other parameters such as suspended solids, oil and grease would reduce UV transmission as it can absorb UV radiation, thereby decreasing the treatment efficiency (Norma and Kirankumar, 1996).

2.4.2 Operating Parameters

Operating parameters are those factors that are varied during the treatment process in order to achieve the desired treatment efficiencies. These factors consists of the optical path length of medium (turbidity of the water sample), molar extinction coefficient (dependent on wavelength which is most commonly 220 nm), influent pH level, concentration of the substrate (contaminant), hydrogen peroxide dose and the intensity and wavelength of the light source used (Melanie et al., 1998, Metcalf and Eddy, 2004, Norma and Kirankumar, 1996).

3.1 Ultraviolet (UV) Lamp

Intensity and wavelength of the UV lamp can affect the treatment efficiency. Journal and articles reviewed stated that the removal efficiency of COD and colour become higher when the combination of UV radiation and hydrogen peroxide is used during the test compared to UV radiation alone.

3.2 Hydrogen Peroxide (H_2O_2) Dose

Hydrogen peroxide is the source of $OH^{\bullet}$ radicals. Thus, the production of $OH^{\bullet}$ radicals will be dependent on the dose of the hydrogen peroxide itself. The leachate will be treated with different dosage of hydrogen peroxide (H_2O_2). This is to evaluate the effect of H_2O_2 concentration to the treatment efficiency.

3.3 Initial pH level

pH is also one of the parameters that govern the efficacy of UV/H_2O_2 treatment. Optimum pH for UV/H_2O_2 treatment is dependent on the characteristics of the sample that will be treated. Reported studies in literature indicate that UV/H_2O_2 treatment is more efficient when it is done in high concentration of hydrogen peroxide and low pH solution for the removal of chemical oxygen demand (COD) and colour (Josmaria and Patricio, 2005, Daneshvar et al., 2008). As to know the effect of pH for both COD and colour removal, the test will be done by varying the pH values in both acidic ranges (2 – 4) and also alkaline range (7 – 9). Since the initial pH of leachate sample from Pulau Burung Landfill Site is in range between 8.4 and 9.1, Sulphuric Acid and Sodium Hydroxide are needed for the pH adjustment. Table 2.2 shows the chemicals that commonly used to adjust pH.

Table 2.2: Common Chemicals Used for the Control of pH (Neutralisation)

Chemicals used to lower pH					
Chemical	Formula	Molecular Weight	Equivalent Weight	Availability	
				Form	Percent
Carbonic acid	H_2CO_3	62.0	31.0	Gas (CO_2)	
Hydrochloric acid	HCl	36.5	36.5	Liquid	27.9, 31.45, 35.2
Sulphuric acid	H_2SO_4	98.1	49.0	Liquid	77.7 93.2

(Metcalf and Eddy, 2004)

2.5 Related Research

In recent years, researchers have tried several AOPs for the pre-treatment of landfill leachate in order to improve biodegradability, remove COD and colour of the leachate (Tizaoui et al., 2007; Petruzzelli et al., 2005; Yang and Englehardt, 2008). Using hydrogen peroxide-enhanced iron-mediated (IMA), (Yang and Englehardt, 2008) has found that aeration rate, H_2O_2 addition rate, iron grade and initial pH have significant influences on COD removal efficiency and iron consumption in matured leachate treatment.

Tizaoui et al. (2007) showed that ozone efficacy was almost double when combined with hydrogen peroxide for the treatment of landfill leachate. The leachate biodegradability was increased from 0.1 to 0.7 by the used of O_3/H_2O_2 system. Fenton's oxidation enhanced 63% of leachate biodegradability where by the BOD_5/COD increased from 0.22 to 0.36, (Petruzzelli, 2007).

Shu et al. (2005) had designed a thin gap annular photoreactor for UV/H_2O_2 process for the purpose of removing the chemical oxygen demand and decolour the landfill leachate. The treatment results shows that 72% and 65% of colour and COD removal was achieved when the leachate was treated with maximum dosage of 4-UV lamps and 232.7mM of hydrogen peroxide concentration for 300min. A comparison between two advance oxidative process ($Fe^{2+}/H_2O_2/UV$ and H_2O_2/UV systems) was done for the pre-treatment of matured landfill leachate. Both methods demonstrated suitability for partial removal of total organic carbon (TOC), chemical oxygen demand (COD) and colour at optimised experimental conditions (Josmaria and Patricio, 2005). Shown in Table 2.3 are the characteristics of the leachate from Pulau Burung Landfill Site based on a previous study (Aghamohammadi et al., 2007).

Table 2.3: Characteristics of leachate collected from Pulau Burung Landfill Site [a]

Parameters	Range	Average	Effluent standard B[b]
pH	8.3-8.8	8.5	5.5-9.0
TCOD (mg/L)	2533-2880	2860	100
SCOD (mg/L)	2310-2850	2360	-
BOD_5 (mg/L)	252-760	377	50
BOD_5 / TCOD	0.09-0.26	0.17	0.5
Alkalinity (mg/L as $CaCo_3$)	5658-5662	5660	-
Colour	4000-4560	4200	-
TKN (mg/L)	1440-2191	1745	-
Ammoniacal Nitrogen (mg/L)	1188-1812	1400	-
NO_2-N (mg/L)	20-110	40	-
NO_3-N (mg/L)	1-50	14.2	-
Turbidity	418-420	419	-
Sulphate (mg/L SO_4^{2-})	90-110	100	-
Phosphate (mg/LPO_4^{3-})	38-40	39	-
Total Suspended Solid (mg/L)	78-80	79	100
Fe (mg/L)	6.1-19	6.6	5.0
Zn (mg/L)	2.06	2.06	1.0
Pb (mg/L)	3.4	3.4	0.5

Source: Aghamohammadi et al., 2007

[a] Based on 12 samplings in 6 months (from 1st April 2005 to 1st October 2005)

[b] Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979, under the Laws of Malaysia Environmental Quality Act 1974 (MDC, 1997). Standard B refers to discharges outside catchment area.

2.6 Design Expert Software

Design-Expert software offers powerful evaluation capability for generations of various statistical measures on the design matrix. It helps user to set up and analyze different class of design such as two-level factorial, general factorial, and combined mixture or process designs, as well as response surface methods (RSM) analysis for up to 10 process factors or 24 mixture components. Response Surface Methods (RSM) is suitable for this study as it can be used to find the ideal process setting. It quantifies relationships among one or more measured response and number of input factors. It also provides sophisticated maps from which peak performance can be identified.

The analysis includes standard ANOVA as well as various diagnostic plots on the residuals. The regression engine handles up to a full cubic polynomial model with forward, backward or stepwise algorithms. The program generates 2D contour plots and rotatable 3D graphs. For this project, Three-Level Factorial design was used to design the experiment and analyses the experiment data.

CHAPTER 3
METHODOLOGY

3.1 Research Methodology

The research starts with sample collection and characterisation, followed by preliminary experiments on the effect of pH adjustment on leachate characteristics before UV-Hydrogen Peroxide (UVHP) treatment. Then, the effectiveness of the UVHP system for the treatment leachate was determined by measuring the reduction of colour, COD and BOD_5. Figure 3.1 shows the tasks or important works covered through out the research.

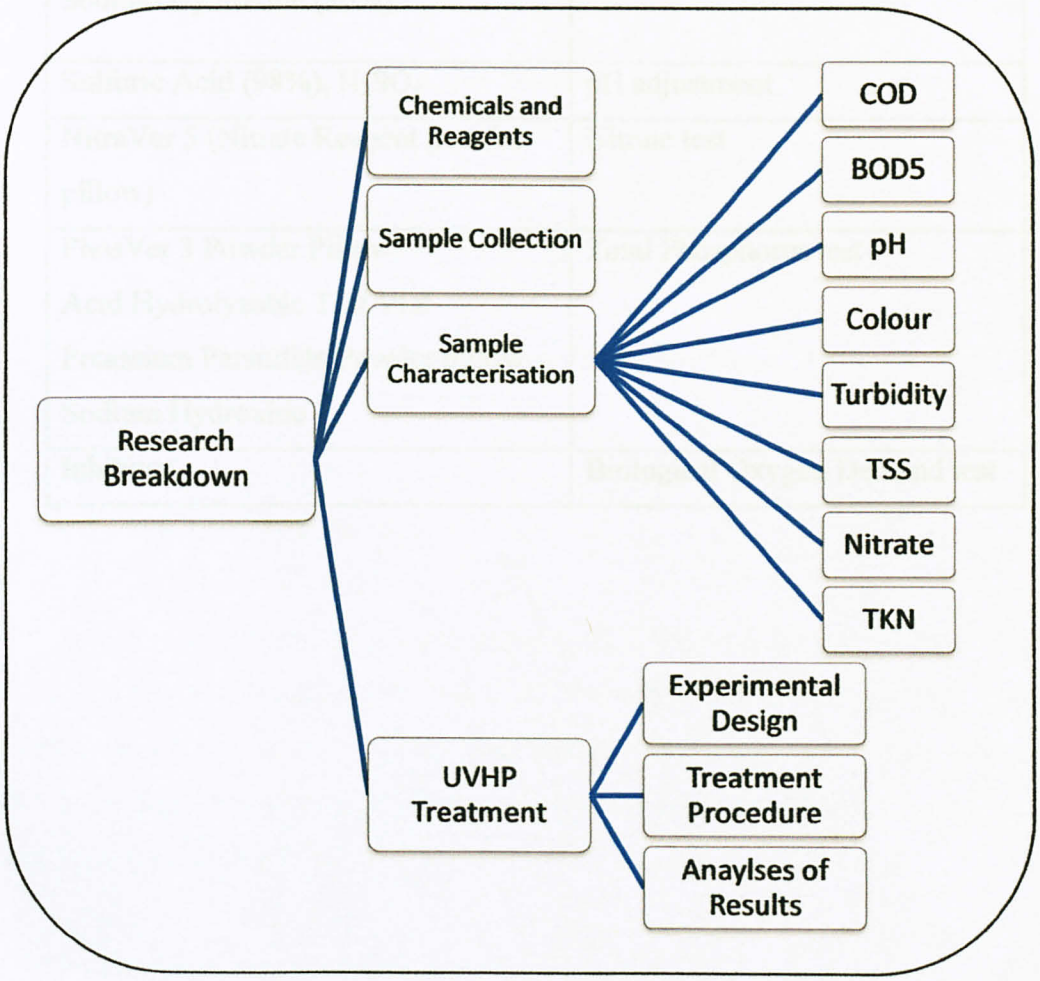

Figure 3.1: Research Breakdown Chart

3.1.1 Chemicals and Reagents

Table 3.1: Chemicals and Reagents

Name of Chemical/Reagent	Purpose of Use
COD vials, HATCH (High Range)	Chemical Oxygen Demand test
Polyvinyl Alcohol Dispersing Agent Nessler Reagent Mineral Stabilizer	Ammonia Nitrogen
Hydrogen peroxide (30%)	UV- Hydrogen Peroxide treatment
Boric Acid (4%) Sodium Hydroxide (30%)	Total Kjeldahl Nitrogen
Sulfuric Acid (98%), H_2SO_4	pH adjustment
NitraVer 5 (Nitrate Reagent powder pillow)	Nitrate test
PhosVer 3 Powder Pillow Acid Hydrolyzable Test Vial Potassium Persulfate Powder pillow Sodium Hydroxide	Total Phosphorus test
Inhibitor	Biological Oxygen Demand test

3.1.2 Sample Collection

The sample of leachate for this project was collected from Pulau Burung Landfill Site, Nibong Tebal, Penang. The sample was transported to the laboratory in sealed plastic barrel, then stored at 4°C before being used and analysed. Show in Figure 3.2 is one of the leachate collection ponds in Pulau Burung Landfill Site.

Figure 3.2: Leachate Collection Pond

3.1.3 Sample Characterisation

Leachate characterisation test such as pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD_5), Total Suspended Solid (TSS), Total Kjeldhal Nitrogen (TKN), colour, turbidity and nitrate were conducted to determine its quality. Further analysis will be done as to know the biodegradability and degree of stabilisation of the leachate.

3.1.3.1 Measurement of Chemical Oxygen Demand, COD

Hach High Range (1-1500) COD vials, were used to measure COD directly using a direct reading spectrophotometer (DR2800). A 2 mL of the diluted sample was added into the vials, and then it was heated in the heating block for two hours at

150°C. The reading can be taken after the vials had been cool down into the room temperature. According to literature, the standard COD test will be interfered if a water or wastewater samples contains hydrogen peroxide. This is because of the dichromate ions react with H_2O_2 in an acidified solution (Huseyin et al., 2006). In order to stop the hydrogen peroxide reaction, pH of the treated leachate is raised to 11, then it was leaved for one night before the sample was analysed. By raising the pH up to 11, the hydrogen peroxide will be converted to oxygen and water.

3.1.3.2 Measurement of Biological Oxygen Demand, BOD_5

For BOD_5 test, 1 mL seed (influent from UTP sewage treatment plant) and 8 mL of leachate were added into 300ml BOD bottles. Aerated distilled water was added into the BOD bottle before the initial DO had been measured. After 5 days incubation, the final DO was measured by using the DO probe.

3.1.3.3 Measurement of pH

pH value was directly determined using the pH meter. The pH meter was calibrated before use as to ensure the accuracy of the pH meter.

3.1.3.4 Measurement of Colour

The colour was determined by a dilution method. The sample was diluted by distilled water for a few dilution factors as to determine the best dilution factor which is right for colour measurement. Reading given by the spectrophotometer was in PtCo unit.

3.1.3.5 Measurement of Turbidity

Turbidity was determined directly using turbidimeter. Figure 3.6 shows the diluted samples for the turbidity as well as colour test. The measurement of turbidity is based on comparison of the intensity of light scattered by a sample to the light scattered by a reference suspension under the same condition (Standard Method, 1998).

3.1.3.6 Measurement of Total Suspended Solid, TSS

This test was done for a few times with different dilution factors. After the sample was poured into the filter flask, the beaker which contained the sample before was rinsed with distilled water in order to ensure all suspended solid had been pour into the filter flask.

3.1.3.7 Measurement of Nitrate

Cadmium reduction method was used in order to determine the nitrate in leachate sample. NitraVer 5 Nitrate Reagent Powder Pillow was added to 10 mL sample before it had been shaken and allowed to react for 5 minutes. The amount of Nitrate was measured directly using the spectrophotometer.

3.1.3.8 Measurement of Total Kjeldahl Nitrogen, TKN

There were three stages involve in total kjeldahl nitrogen test which were digestion, cooling and distillation stage. 15 ml of diluted and undiluted sample was placed in a 600ml Kjeldahl flask. 0.25 g of selenium and 20 ml of concentrated sulphuric acid were added into the flask. The mixture was digested on the digestion rack until all the sulphur gas evaporated. The digestion process took time for about 50 minutes while the cooling process was 30 minutes. The distillation process was done using auto sampler where the final output were titration volume of acid and value for blank. The output was used in the calculation part as to calculate the value of total kjeldahl nitrogen.

3.1.4 UV- Hydrogen Peroxide Treatment

Batch reactor was used in the UV/Hydrogen Peroxide treatment system. The laboratory experiments were done in order to evaluate the influence of process operating parameters such as pH, H_2O_2 concentration, and reaction time. In this experiment, colour, Chemical Oxygen Demand, and Biological Oxygen Demand were monitored. Figures 3.3 and 3.4 show the schematic diagram of the reactor and the reactor that was used in the laboratory while Table 3.1 shows the specifications of the UV lamp.

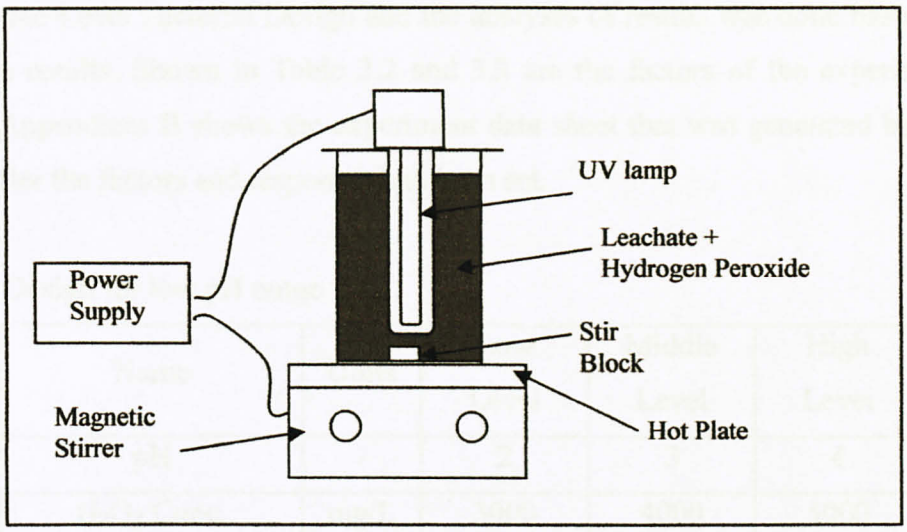

Figure 3.3: Schematic diagram of experimental setup

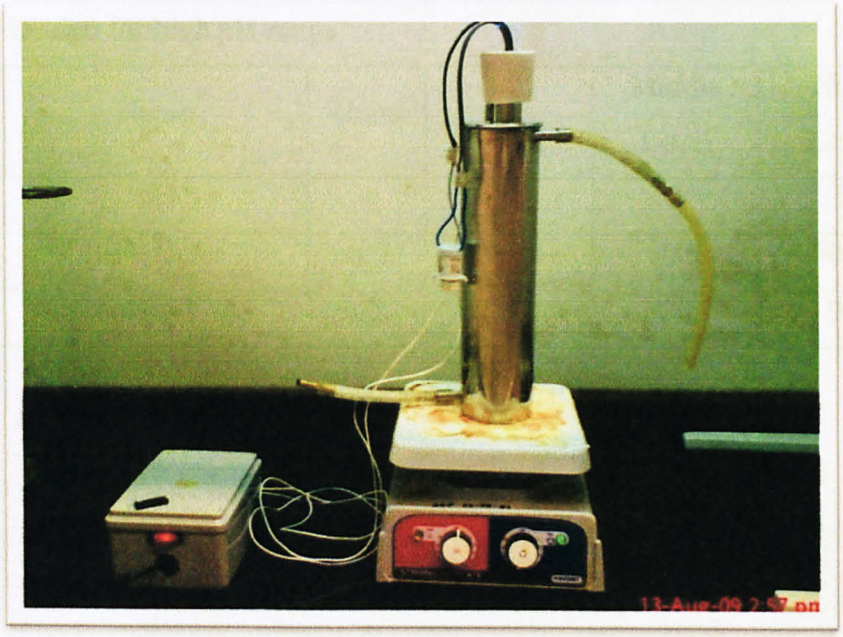

Figure 3.4: UV-Hydrogen Peroxide Reactor

Table 3.2: UV Lamp Specifications

Type	UV-C (Low Pressure)
Wavelength	254 nm
Power	8 W
Cover	Quartz tube

3.1.4.1 Experimental Design

The experiments were designed based on Response Surface Methodology (RSM), Three-Level Factorial Design and the analyses of results was done based on analyse the results. Shown in Table 3.2 and 3.3 are the factors of the experiment designed. Appendices B shows the experiment data sheet that was generated by the software after the factors and responses had been set.

Table 3.3: Design for low pH range

Factor	Name	Units	Low Level	Middle Level	High Level
A	pH	-	2	3	4
B	H_2O_2 Conc.	mg/L	3000	4000	5000
C	Reaction Time	min	10	50	90

Table 3.4: Design for high pH range

Factor	Name	Units	Low Level	Middle Level	High Level
A	pH	-	7	8	9
B	H_2O_2 Conc.	mg/L	3000	4000	5000
C	Reaction Time	min	10	50	90

The initial pH of leachate from PBLS is in range between 8.4 and 9.1. For the experiment which requires the pH adjustment, either to raise or lower the pH, Sulphuric Acid (98% pure) and Sodium Hydroxide (50%) was added into the leachate. Bubbles and gasses were expected to produce when the acid was added into the leachate as there were some reactions occurs between the acid and the leachate. The sample was filtered before being used in the treatment process as to remove the suspended material in the sample.

3.1.4.2 Treatment Procedures

i. The pH value of 400 mL sample was adjusted to a pH of 2, 3, 4, 7, 8 and 9 before the sample was filtered. The sample is taken to determine the initial chemical oxygen demand, COD and colour.

ii. The filtered sample was added with 3000, 4000 or 5000 mg/L of hydrogen peroxide before it was stirred for 1 minutes.

iii. The sample was placed under irradiation using an 8W low-pressure mercury lamp. The magnetic stirrer was switched on throughout the experiment.

iv. The sample was taken three times (t = 10, 50 and 90 minutes) as to determine the COD and colour. The pH was raised up to pH 11 before the measurement of COD and colour. This is to stop the effect of hydrogen peroxide to the leachate.

v. For the sample at t = 90 minutes, the biological oxygen demand was measured to determine the BOD_5 of the sample after treatment.

3.1.4.3 Analysis of the Results

The efficacy of this pre-treatment can be determined by calculating the percentage of COD and colour removal. By using the Design Expert software, Response Surface Methodology (RSM), the optimum condition for the leachate treatment can be obtained. The effect of process parameters also will be determined.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Sample Characterisation

From the characterisation test that was done in the laboratory, there are some increments in the value of chemical oxygen demand (COD), colour and total kjeldahl nitrogen (TKN) of the leachate. On the other hand, the biological oxygen demand (BOD) was slightly decreased which resulted in lowered the BOD/COD ratio. The comparison between the results from the laboratory test, other research and Environmental Quality Act Standard is shown in Table 4.1.

Table 4.1: Leachate Characteristics

Parameters	From Lab Measurement	From Other Research[a]	Effluent Standard B[b]
pH	8.9	8.5	5.5 – 9.0
TCOD (mg/L)	3372	2860	100
SCOD(mg/L)	2980	2360	-
BOD_5 (mg/L)	317	377	50
BOD_5/ TCOD	0.09	0.17	0.5
Colour (PtCo)	4474	4200	-
TKN (mg/L)N	2083	1745	-
NO_3-N (mg/L)	14.0	14.2	-
Total Suspended Solid (mg/L)	40	79	100

[a] Aghamohammadi et al., 2007

[b] Environmental Quality (Sewage and Industrial Effluents Regulations 1979)

From Table 4.1, it is shown that the COD and BOD of the leachate are not complying with EQA standard. BOD/COD is also very low, 0.09 which shows that the biological treatment of leachate is limited.

4.1.1 Turbidity and Colour

As the colour measurements were made on unfiltered samples, the result obtained is apparent colour. The apparent colour includes that from dissolved materials and suspended matter in the leachate. Turbidity is a measure of the light-transmissibility properties of water. High in turbidity will affect the transmission of UV radiation in the leachate. Turbidity and colour was measured for different dilutions as shown in Table D.1 and D.2 (Appendix D). Based on the result obtained, the colour and turbidity are 4203 PtCo and 69.55 (NTU) respectively. For every runs of UV/H_2O_2 treatment, the colour was measured for raw sample and sample after treatment.

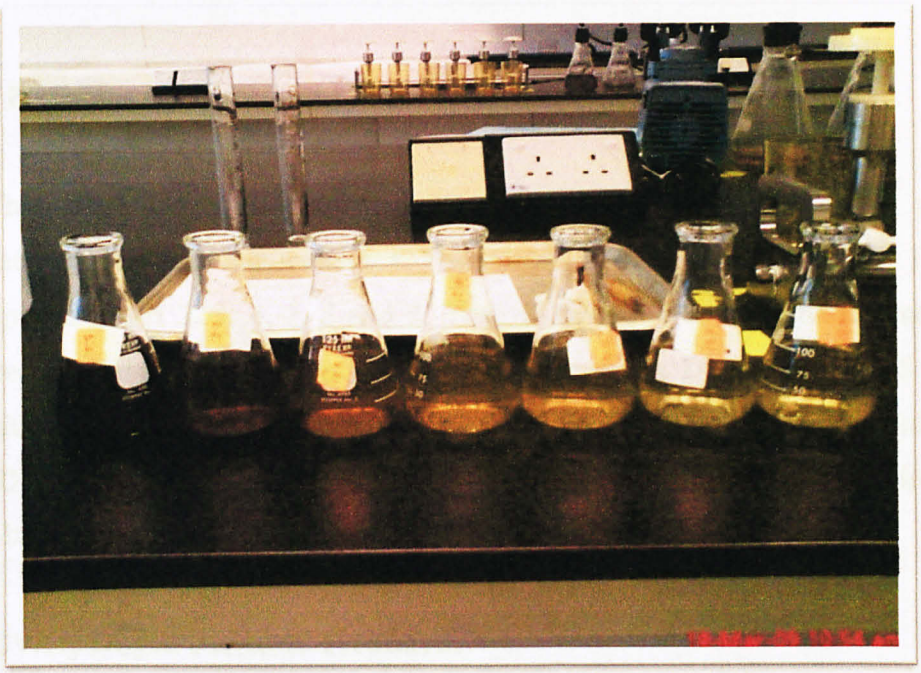

Figure 4.1: Different Dilution of Leachate for Turbidity, Colour and TSS Measurement

4.1.2 Measurement of Total Suspended Solid, TSS

Total Suspended Solid is the portion of the total solid retained on a filter with a specified pore size. It is measured after being dried at a specified temperature (103°C to 105°C). The formula used to calculate TSS is shown in Appendix C (1) whilst data recorded for this test is shown in Appendix D (Table D.3). Based on the result obtained from the lab measurement, average TSS of the leachate is 40 mg/L.

4.1.3 Total Kjeldhal Nitrogen

Total nitrogen consists of organic nitrogen, ammonia, nitrite and nitrate. Kjeldahl method is used to determine the organic nitrogen while total kjeldahl nitrogen will give the value of both organic and ammonia nitrogen. For total kjeldahl nitrogen, the aqueous sample was not boiled before it was digested. This is because the boiling process will drive off the ammonia. The action of heat and acid during the digestion period has converted the organic nitrogen to ammonium. Thus final result will gives the value of both organic and ammonia nitrogen. The formula used to determine TKN value is shown in Appendix C (2) and the data recorded for TKN test is shown in Table D.4 (Appendix D). From the calculation, the value of total kjeldahl nitrogen is 2083 mg/L N.

4.1.4 Preliminary Experiment

This preliminary experiment was done to determine the effect of pH adjustment on leachate characteristics. The initial pH PBLS leachate is 8.9. The pH was adjusted to pH 2, 3, 4, 7, 8 and 9. Then COD and colour of the leachate was measured. Based on data shown in Table D.6 (Appendix D), the COD and colour was reduced after the pH been adjusted to acidic conditions. However, the reduction of COD and colour is not much. This reduction may be due to the precipitation occurs between the added acid and the leachate.

4.2 UV/Hydrogen Peroxide Treatment

In this treatment, the experimental design was based on Three-Level Factorial design where the factors are pH, reaction time and hydrogen peroxide concentration while the responses are colour removal, chemical oxygen demand (COD) removal and BOD/COD ratio. Thus, throughout the experiment, colour, COD and biological oxygen demand (BOD) was measured.

Before start the treatment, the pH of leachate was adjusted to the desired pH. Then, the sample was filtered as to remove the suspended solid or colloid from the leachate. The presence of suspended solid will interfere with UV irradiation during

the treatment. From the experiment that been conducted, the lower the pH, the greater the remaining on the filter paper. Figures 4.2 and 4.3 show the filter paper after the filtration process.

Figure 4.2: Remaining of Sample pH 3

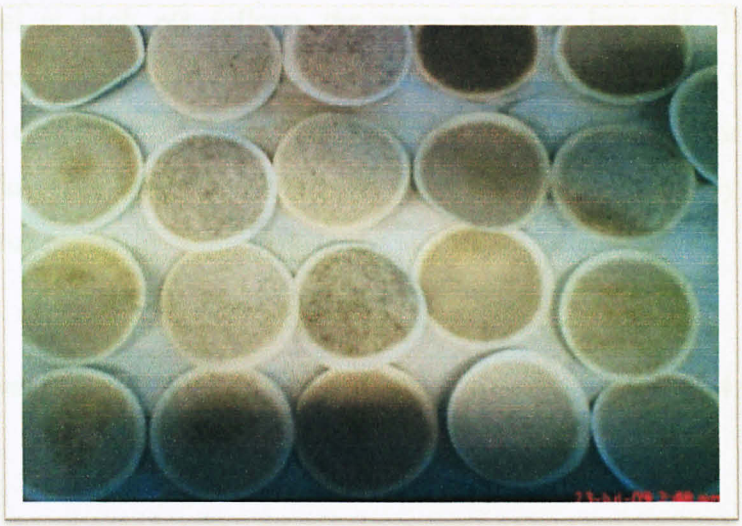

Figure 4.3: Remaining of Sample pH 8

Generally, in determining the effect of pH, the other operating parameter of the system will be constant. It also the same when the effect of hydrogen peroxide was determined, the pH and reaction time become constant. By using design expert software, the total experiment that need to be done was generated randomly with the combination of all the factors that been set earlier. All the data recorded during the experiments are shown in Table D.7 – Table D.12 (Appendix D). By using Design – Expert software, the statistical analysis that been done as shown in Appendix E.

4.2.1 Colour Removal

Table 4.2 shows the analysis of variance for colour removal at low pH range based on Response Surface Quadratic Model. Based on the table, the Model F-value of 33.35 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. The values of "Prob > F" less than 0.05 indicate model terms are significant and values greater than 0.1 indicate the model terms are not significant. For this table, A, B, and C is referred to the factors which are pH, hydrogen peroxide concentration and reaction time. In this case A, B, C, A^2, B^2 are significant model terms. Figure 4.5 shows the graph of predicted vs actual value. Based on this graph, it is shown that the actual value has not much difference with predicted value. Figure 4.6 shows graph of outlier t versus run order. Based on this graph, it is shown that the actual values lies within the outlier limit. Based on Figure E.1.1 and E.1.2 (Appendix E), it is observed that colour removal at high pH follows the same trend as low pH. There is small diffrence between the actual value and predicted value. Besides, there is no outlier in these sets of experiment. Based on ANOVA, a model of colour removal for treatment at low pH range has been develop and this model only includes the significant terms.

$$\text{Colour Removal (\%)} = 78.01 - 15.47A + 4.98B + 10.27C - 18.69A^2 - 4.99B^2 - 2.98C^2 - 2.98AB - 1.54AC + 1.23BC$$

where

A: pH

B: Hydrogen Peroxide Concentration, mg/L

C: Reaction Time, min

Table 4.2: Analysis of variance table (Partial Sum of Squares) for Colour Removal at Low pH Range

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	10435.143	9	1159.46	33.348	< 0.0001	significant
A	4307.193	1	4307.19	123.885	< 0.0001	
B	446.662	1	446.66	12.847	0.0017	
C	1898.667	1	1898.66	54.610	< 0.0001	
A^2	2497.698	1	2497.69	71.839	< 0.0001	
B^2	178.088	1	178.08	5.122	0.0338	
C^2	63.578	1	63.57	1.828	0.1900	
AB	106.292	1	106.29	3.0572	0.0943	
AC	28.379	1	28.37	0.816	0.3761	
BC	18.163	1	18.16	0.522	0.4774	
Residual	764.887	22	34.76			

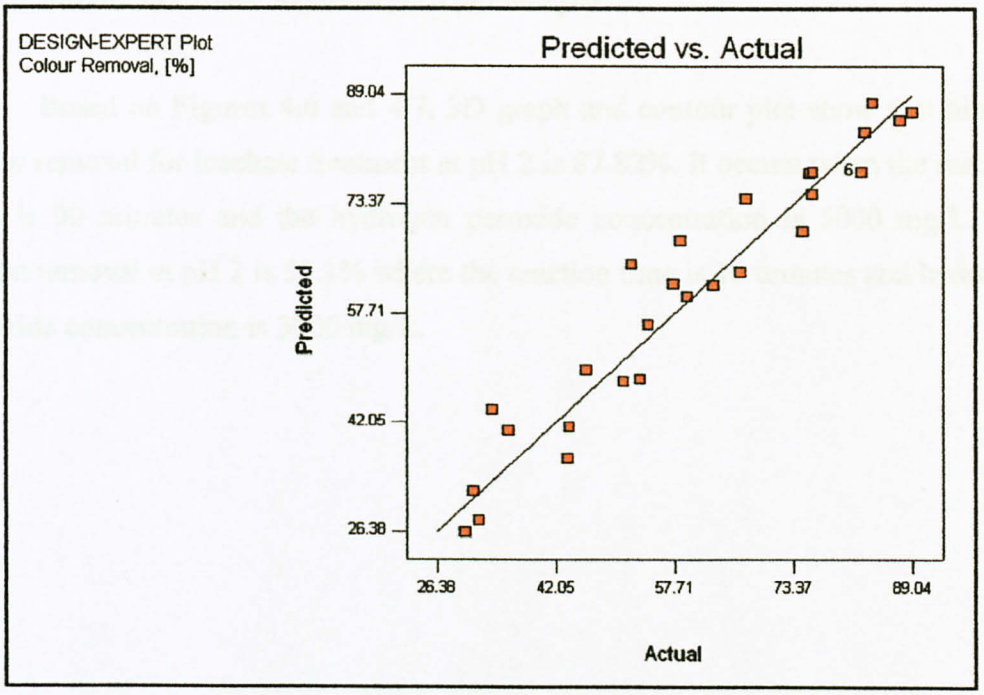

Figure 4.4: Predicted vs. Actual Plot for Colour Removal at Low pH Range

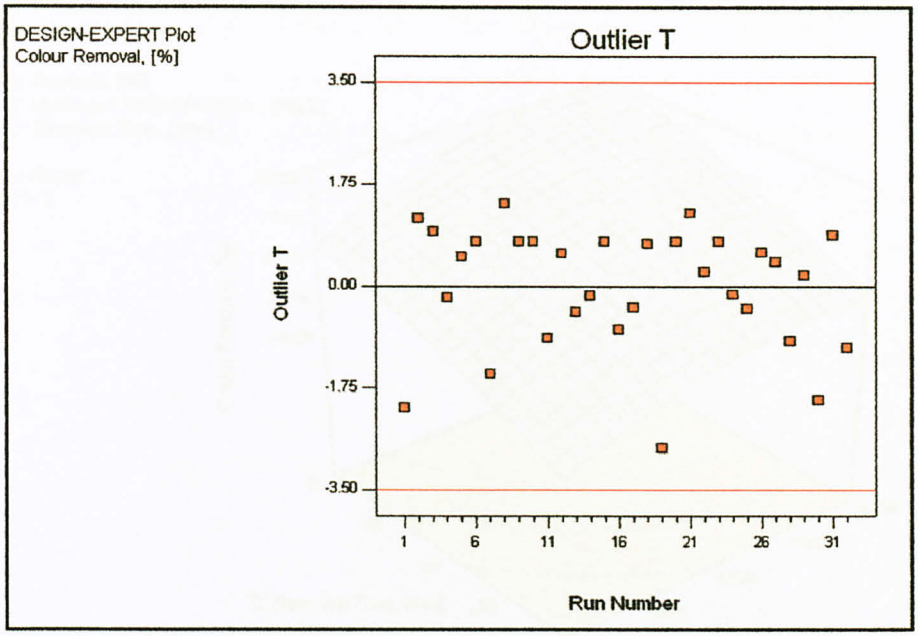

Figure 4.5: Outlier T vs. Run Order Plot for Colour Removal at Low pH Range

4.2.1.1 Results of Colour Removal for Different pH

Based on Figures 4.6 and 4.7, 3D graph and contour plot show that highest colour removal for leachate treatment at pH 2 is 87.82%. It occurs when the reaction time is 90 minutes and the hydrogen peroxide concentration is 5000 mg/L. The lowest removal at pH 2 is 53.1% where the reaction time is 10 minutes and hydrogen peroxide concentration is 3000 mg/L.

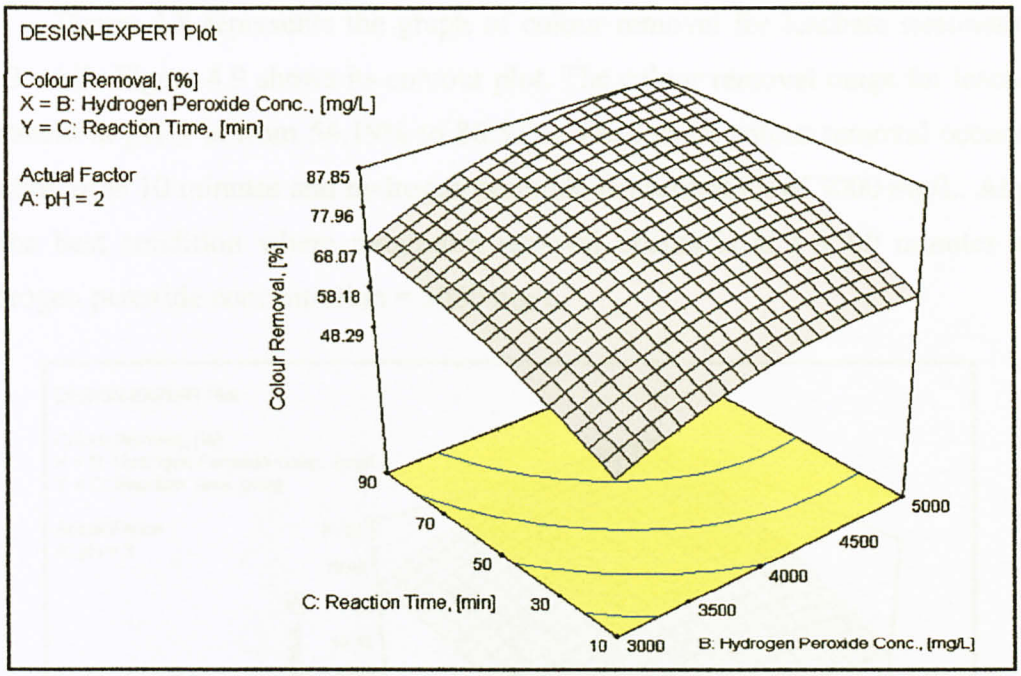

Figure 4.6: 3D Graph of Colour Removal at pH 2

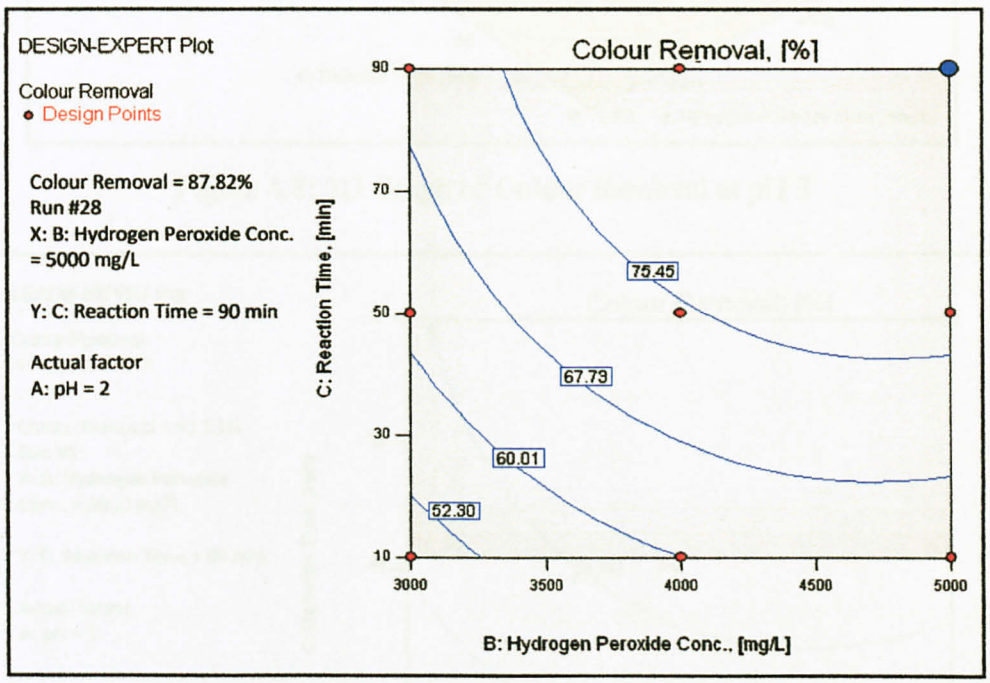

Figure 4.7: Contour plot of Colour Removal at pH 2

Figure 4.8 represents the graph of colour removal for leachate treatment at pH 3 while Figure 4.9 shows its contour plot. The colour removal range for leachate treatment at pH 3 is from 54.19% to 86.53%. The lowest colour removal occurs at reaction time 10 minutes and hydrogen peroxide concentration of 3000 mg/L. At pH 3, the best condition where maximum removal occurs is at t = 90 minutes and hydrogen peroxide concentration = 5000 mg/L.

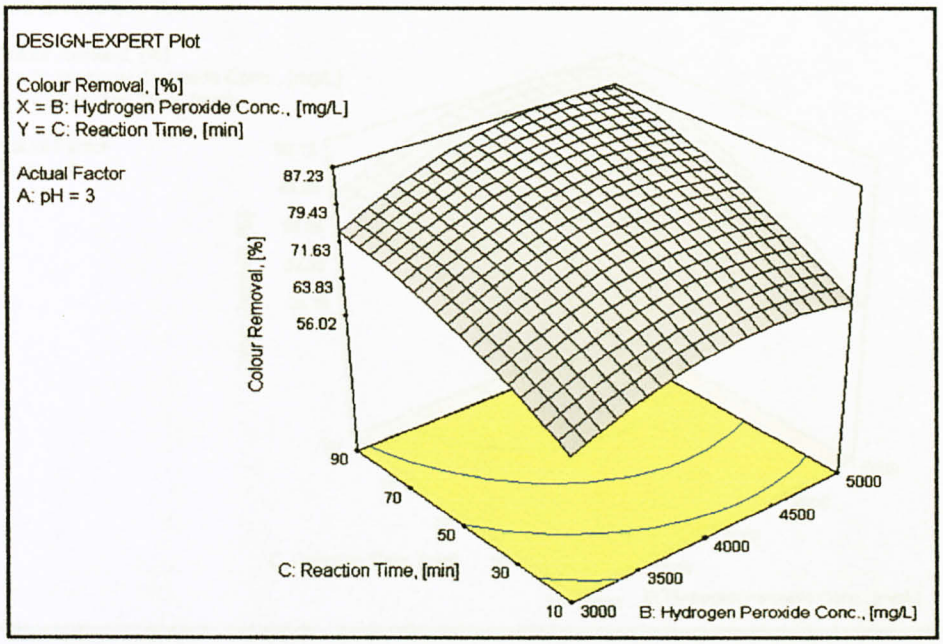

Figure 4.8: 3D Graph of Colour Removal at pH 3

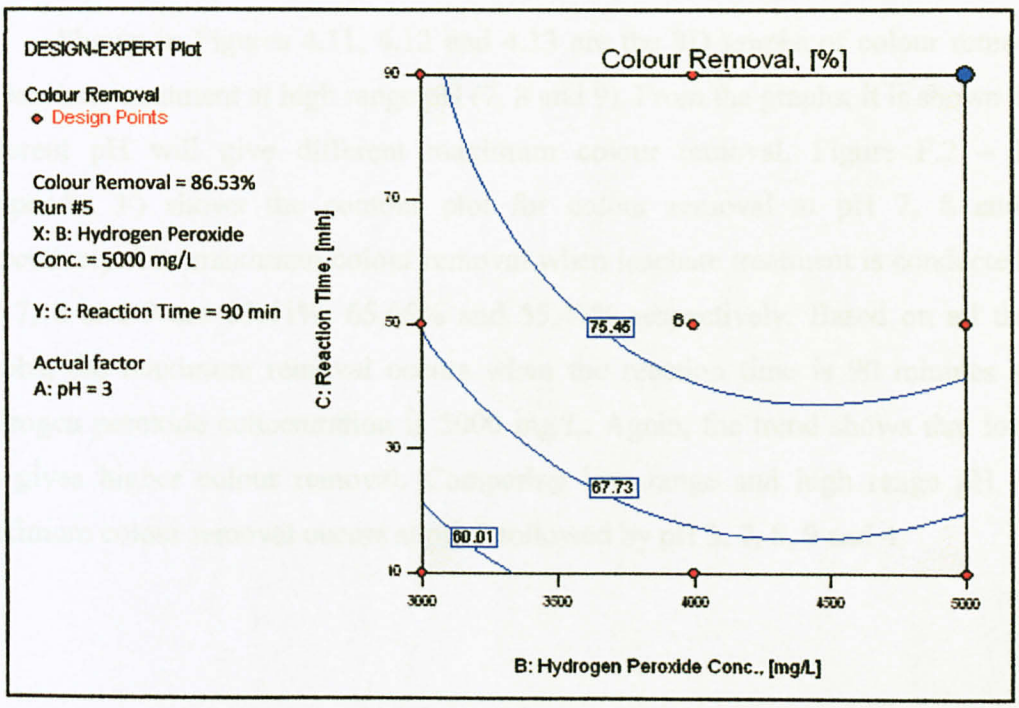

Figure 4.9: Contour plot of Colour Removal at pH 3

Based on Figure 4.10, the maximum colour removal for leachate treatment conducted at pH 4 is achieved when the reaction time is at 90 minutes and hydrogen peroxide concentration at 4000 mg/L. Referring to contour plot shown in Figure F.1 (Appendix F), the maximum colour removal 49.61% while the minimum colour removal is 26.38%.

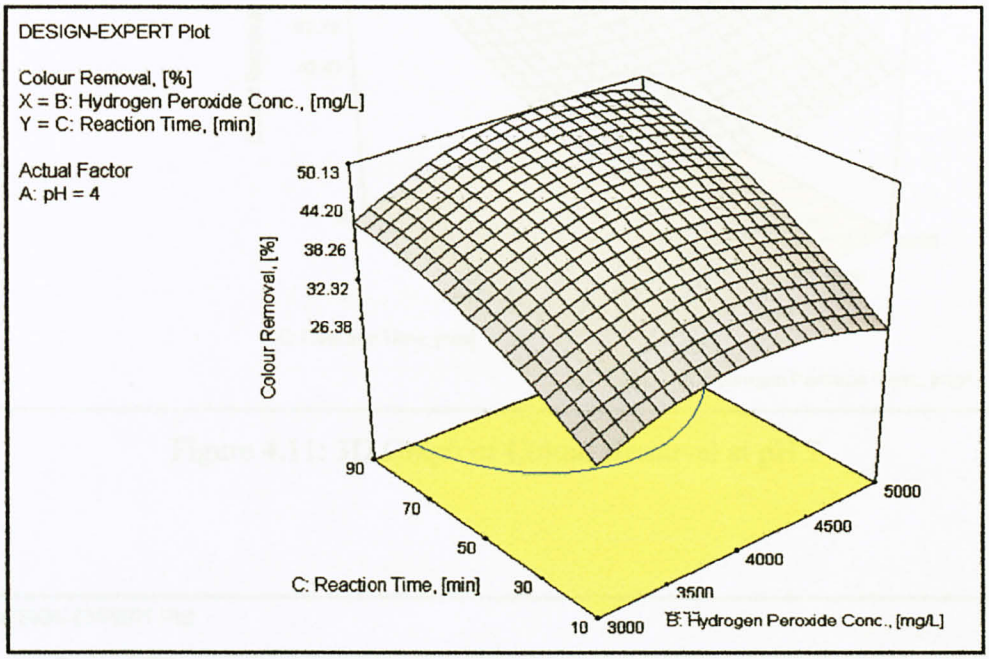

Figure 4.10: 3D Graph of Colour Removal at pH 4

Shown in Figures 4.11, 4.12 and 4.13 are the 3D graphs of colour removal for leachate treatment at high range pH (7, 8 and 9). From the graphs, it is shown that different pH will give different maximum colour removal. Figure F.2 – F.4 (Appendix F) shows the contour plot for colour removal at pH 7, 8 and 9 respectively. The maximum colour removal when leachate treatment is conducted at pH 7, 8 and 9 are 83.41%, 65.65% and 55.47% respectively. Based on all three graphs, the maximum removal occurs when the reaction time is 90 minutes and hydrogen peroxide concentration is 5000 mg/L. Again, the trend shows that lower pH gives higher colour removal. Comparing low range and high range pH, the maximum colour removal occurs at pH 2 followed by pH 3, 7, 8, 9 and 4.

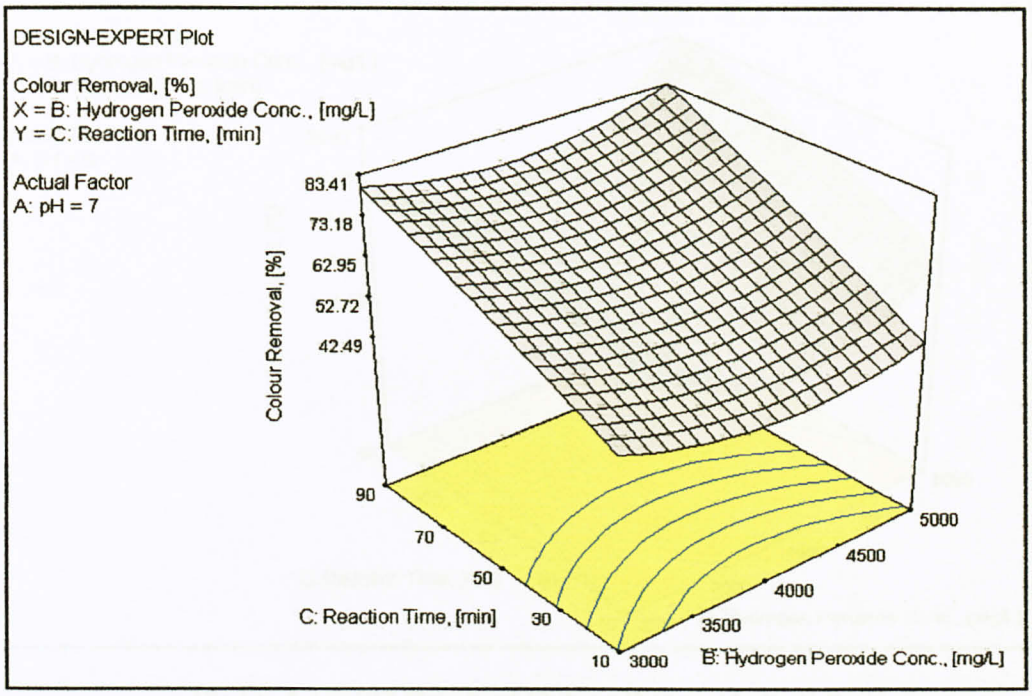

Figure 4.11: 3D Graph of Colour Removal at pH 7

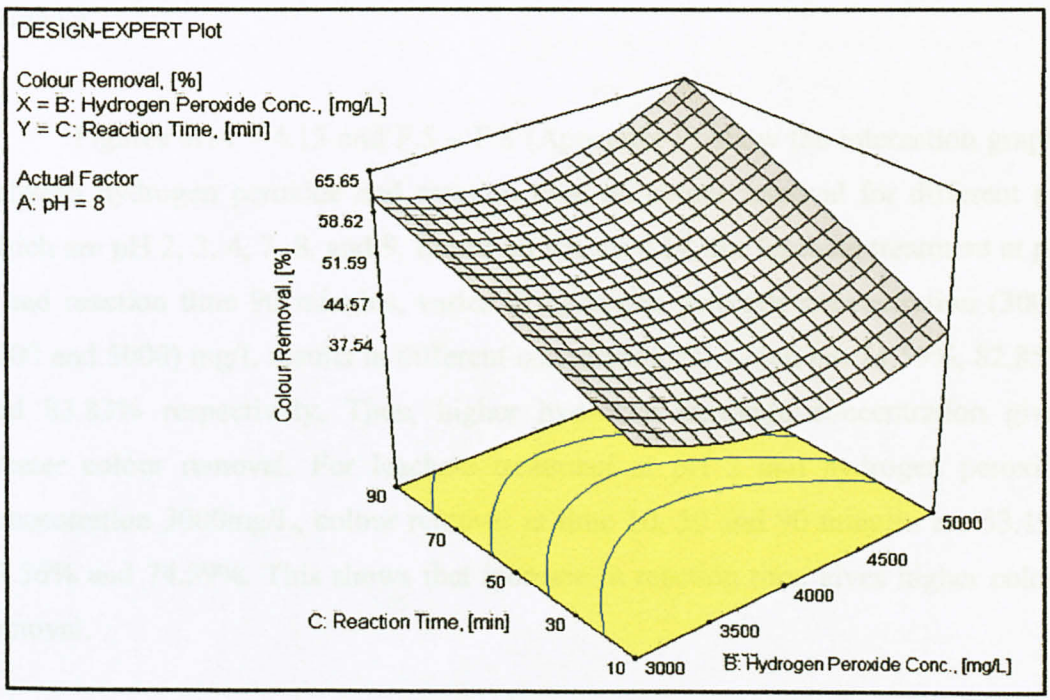

Figure 4.12: 3D Graph of Colour Removal at pH 8

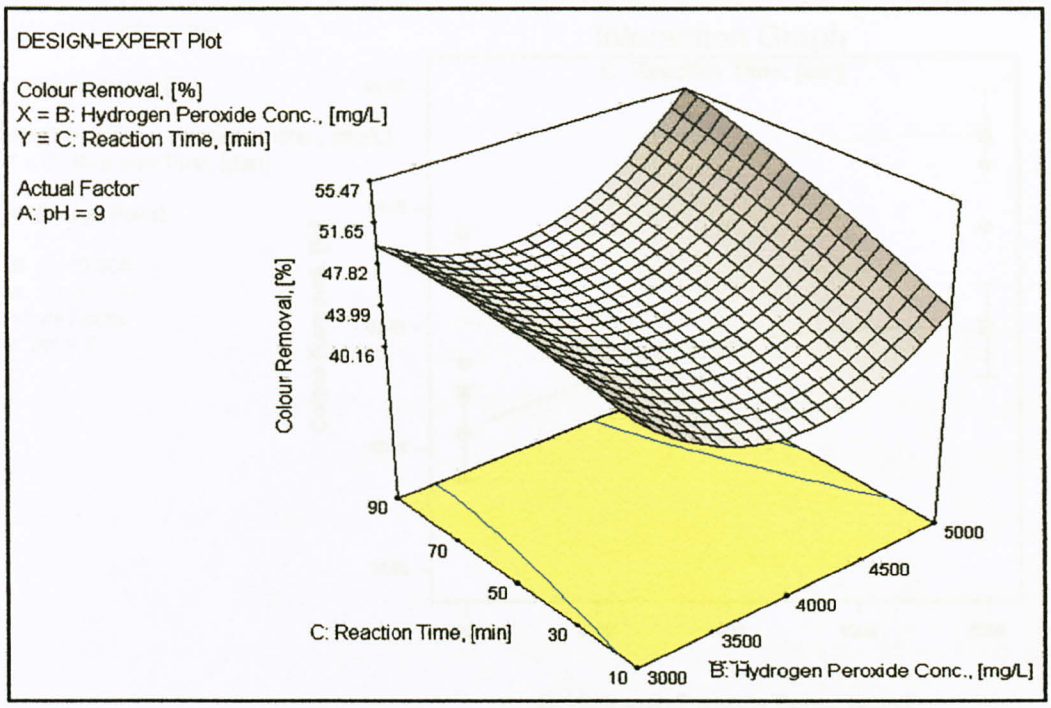

Figure 4.13: 3D Graph of Colour Removal at pH 9

4.4.1.2 Effect of Hydrogen Peroxide Concentration and Reaction Time on Colour Removal

Figures 4.14 – 4.15 and F.5 – F.8 (Appendix F) show the interaction graphs between hydrogen peroxide and reaction time on colour removal for different pH which are pH 2, 3, 4, 7, 8, and 9. Based on Figure 4.14, for leachate treatment at pH 2 and reaction time 90 minutes, varies in hydrogen peroxide concentration (3000, 4000 and 5000) mg/L results in different colour removal which are 74.59%, 82.85% and 83.83% respectively. Thus, higher hydrogen peroxide concentration gives greater colour removal. For leachate treatment at pH 2 and hydrogen peroxide concentration 3000mg/L, colour removal at time 10, 50 and 90 minutes are 53.1%, 57.56% and 74.59%. This shows that increase in reaction time gives higher colour removal.

Figures 4.14 - 4.15 represent the interaction graphs of colour removal for pH 2 and 3 while Figures F.5 – F.8 (Appendix F) represent the interaction graphs for pH 4, 7, 8 and 9. Based on the graphs, the effects of hydrogen peroxide and reaction time on colour removal seems to be quite similar.

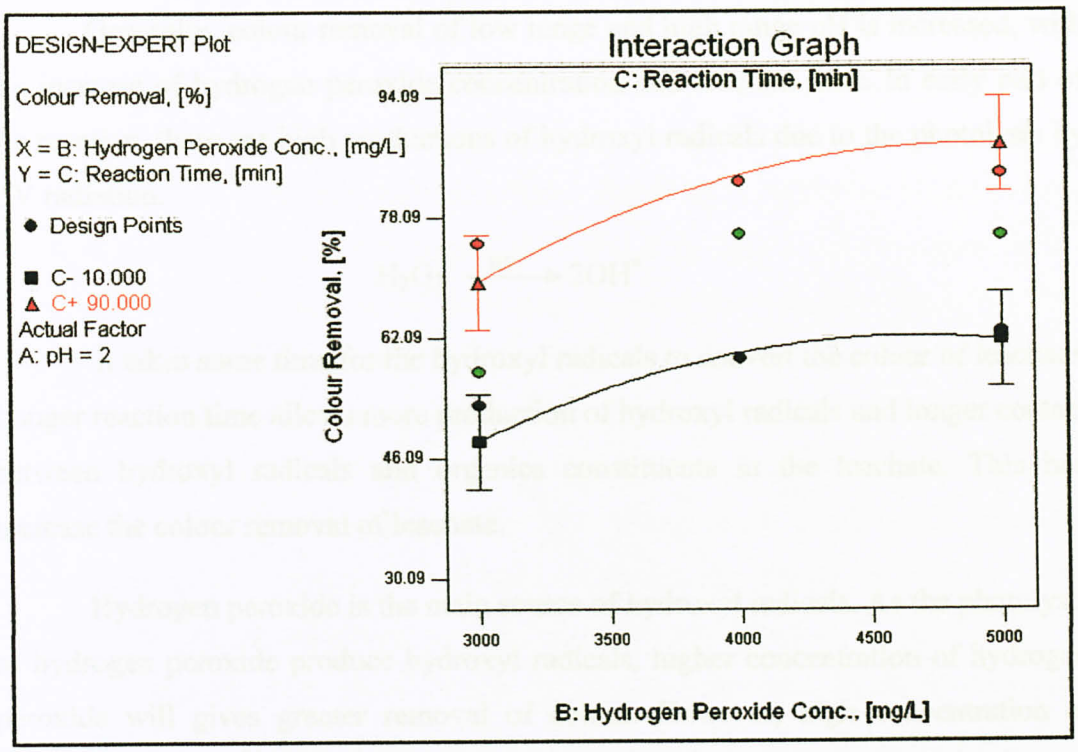

Figure 4.14: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on Colour Removal at pH 2

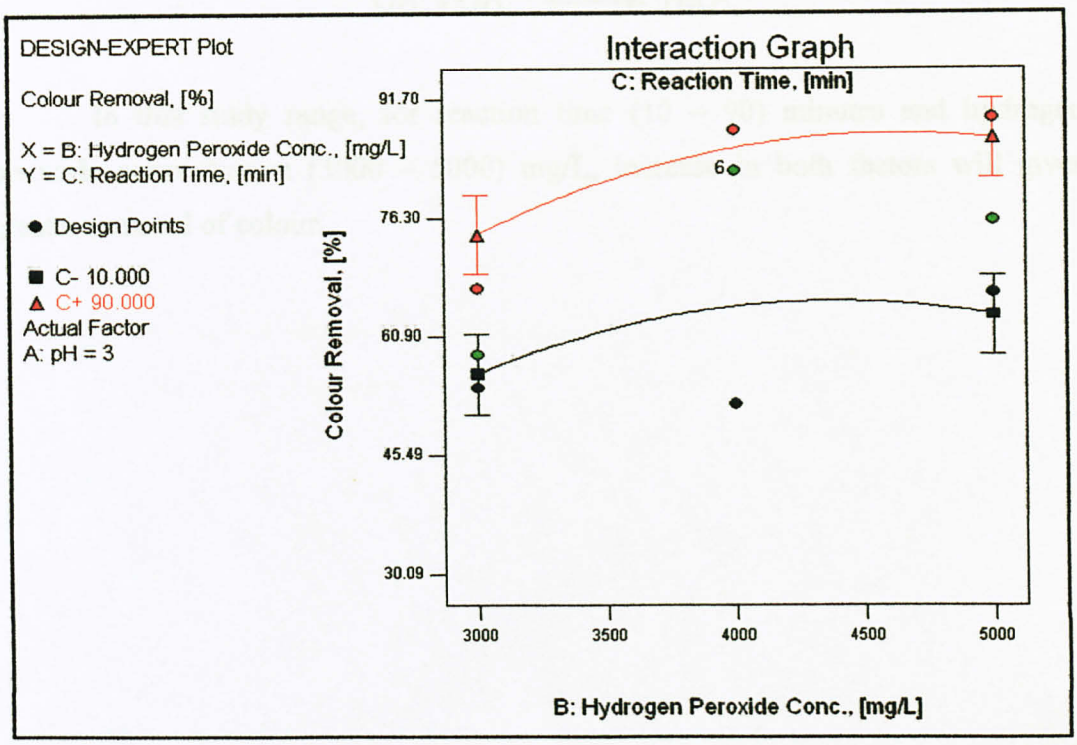

Figure 4.15: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on Colour Removal at pH 3

Generally, colour removal of low range and high range pH is increased, with the increase of hydrogen peroxide concentration and reaction time. In early part of the reaction, there are high productions of hydroxyl radicals due to the photolysis by UV radiation.

$$H_2O_2 \xrightarrow{uv} 2OH^{\bullet}$$

It takes some time for the hydroxyl radicals to convert the colour of leachate. Longer reaction time allows more production of hydroxyl radicals and longer contact between hydroxyl radicals and organics constituents in the leachate. This had increase the colour removal of leachate.

Hydrogen peroxide is the main source of hydroxyl radicals. As the photolysis of hydrogen peroxide produce hydroxyl radicals, higher concentration of hydrogen peroxide will gives greater removal of colour. However, high concentration of hydrogen peroxide may lead to excess production of hydroxyl radical. This may reduce the efficacy of the treatment as the hydroxyl radical tends to react with each other and combined to form a stable product.

$$OH^{\bullet} + OH^{\bullet} \longrightarrow H_2O_2$$

In this study range, for reaction time (10 – 90) minutes and hydrogen peroxide concentration (3000 – 5000) mg/L, increase in both factors will gives greater removal of colour.

4.2.2 COD Removal

Table 4.3 shows the analysis of variance for COD removal at low pH range based on Response Surface Quadratic Model. Based on the table, the Model F-value of 74.55 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. The values of "Prob > F" less than 0.0500 indicate model terms are significant and values greater than 0.1000 indicate the model terms are not significant. For this table, A, B, and C is referred to the factors which are pH, hydrogen peroxide concentration and reaction time. In this case A, B, C, A^2, AB, AC, BC are significant model terms. Figure 4.17 shows the graph of predicted vs actual value. Based on this graph, it is shown that the actual value has not much difference with predicted value. Figure 4.18 shows graph of outlier t versus run order. Based on this graph, it is shown that the actual values lies within the range. There is no outlier in these sets of experiment. Based on Figure E.3 and E.4 (Appendix E), it is shown that the some of actual values have high difference from expect ed values. However, all the values lies within the outlies limit. Based on ANOVA, a model of COD removal has been develop for treatment at low pH range and this model only includes the significant terms.

$$\text{COD Removal (\%)} = 23.53 - 3.36A + 5.03B + 14.2C - 6.27A^2 + 0.08B^2 - 1.82C^2 - 2.69AB - 4.97AC + 4.89BC$$

where

A: pH

B: Hydrogen Peroxide Concentration, mg/L

C: Reaction Time, min

Table 4.3: Analysis of variance table (Partial Sum of Squares) for COD Removal at Low pH Range

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	5334.144	9	592.68	74.5532	< 0.0001	significant
A	203.335	1	203.33	25.5774	< 0.0001	
B	454.518	1	454.51	57.1736	< 0.0001	
C	3630.502	1	3630.50	456.678	< 0.0001	
A^2	281.022	1	281.02	35.3496	< 0.0001	
B^2	0.050	1	0.050	0.0063	0.9374	
C^2	23.675	1	23.67	2.9781	0.0984	
AB	86.676	1	86.67	10.903	0.0032	
AC	296.098	1	296.09	37.2460	< 0.0001	
BC	287.325	1	287.32	36.1424	< 0.0001	
Residual	174.895	22	7.94			

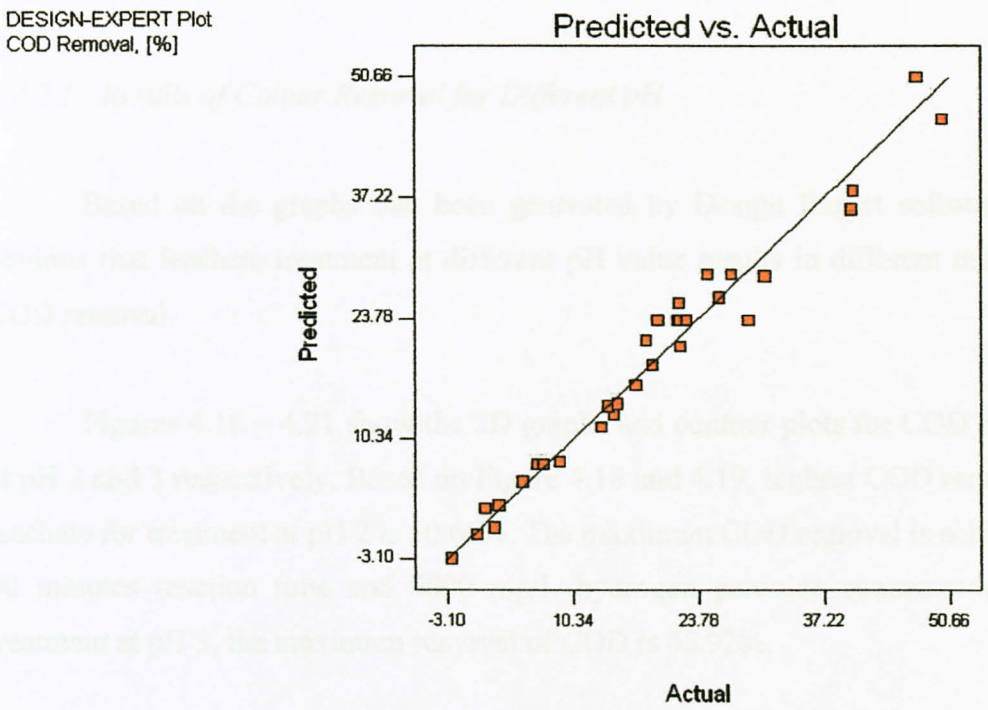

Figure 4.16: Predicted vs. Actual Plot for COD Removal at Low pH Range

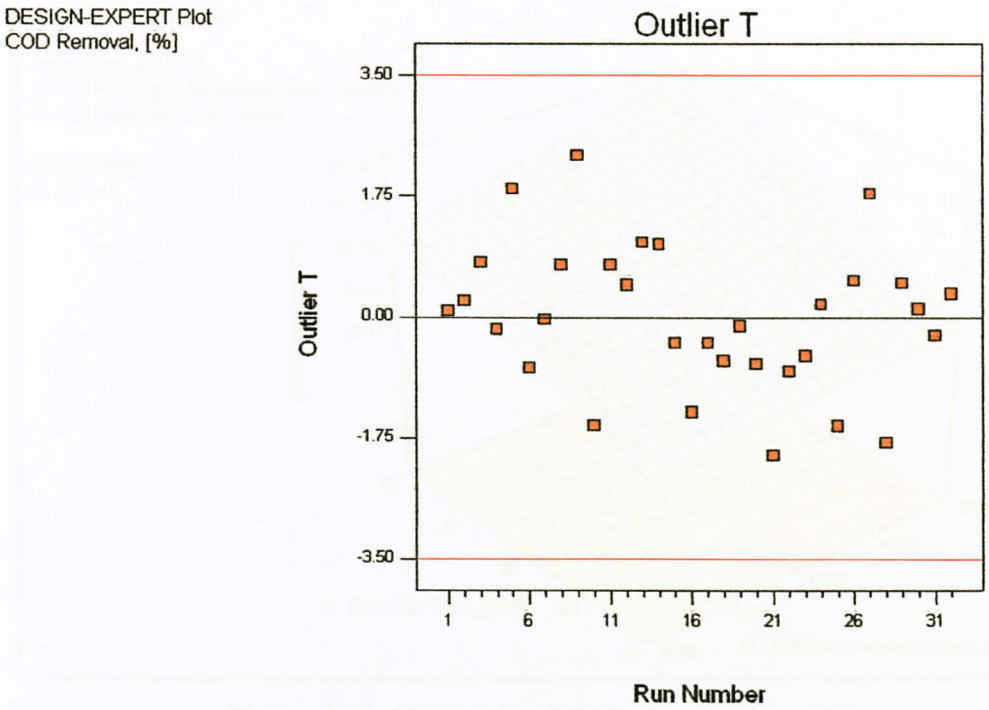

Figure 4.17: Outlier T vs. Run Order Plot for COD Removal at Low pH Range

4.2.2.1. Results of Colour Removal for Different pH

Based on the graphs that been generated by Design Expert software, it is obvious that leachate treatment at different pH value results in different maximum COD removal.

Figures 4.18 – 4.21 show the 3D graphs and contour plots for COD removal at pH 2 and 3 respectively. Based on Figure 4.18 and 4.19, highest COD removal of leachate for treatment at pH 2 is 50.66%. The maximum COD removal is achieved at 90 minutes reaction time and 5000 mg/L hydrogen peroxide concentration. For treatment at pH 3, the maximum removal of COD is 45.92%.

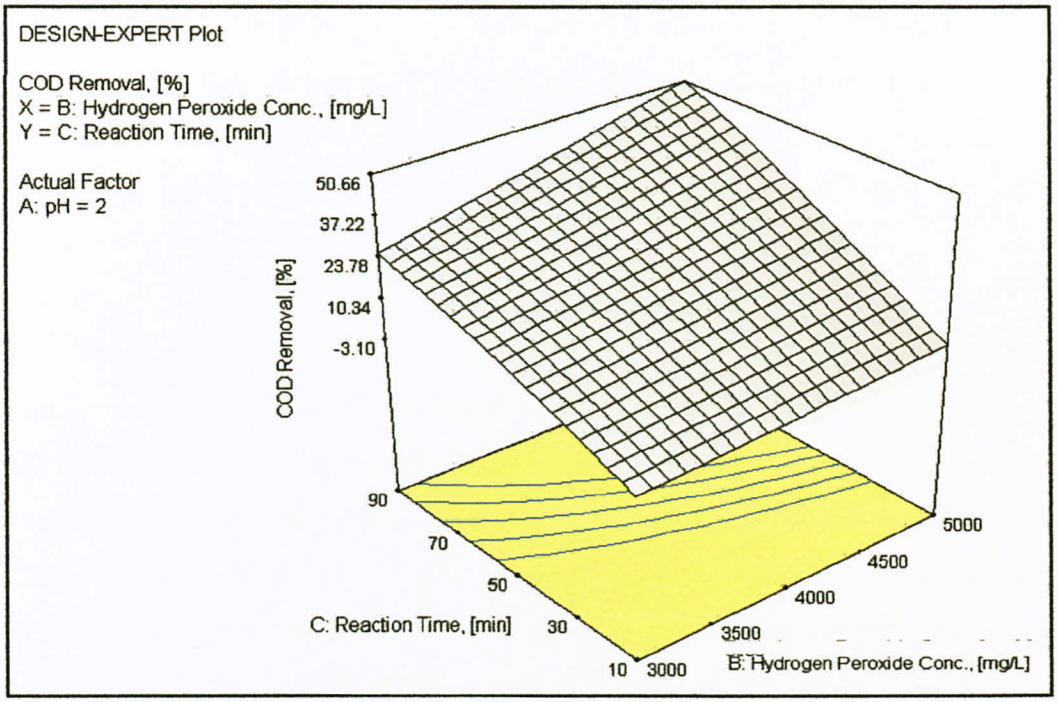

Figure 4.18: 3D Graph of COD Removal at pH 2

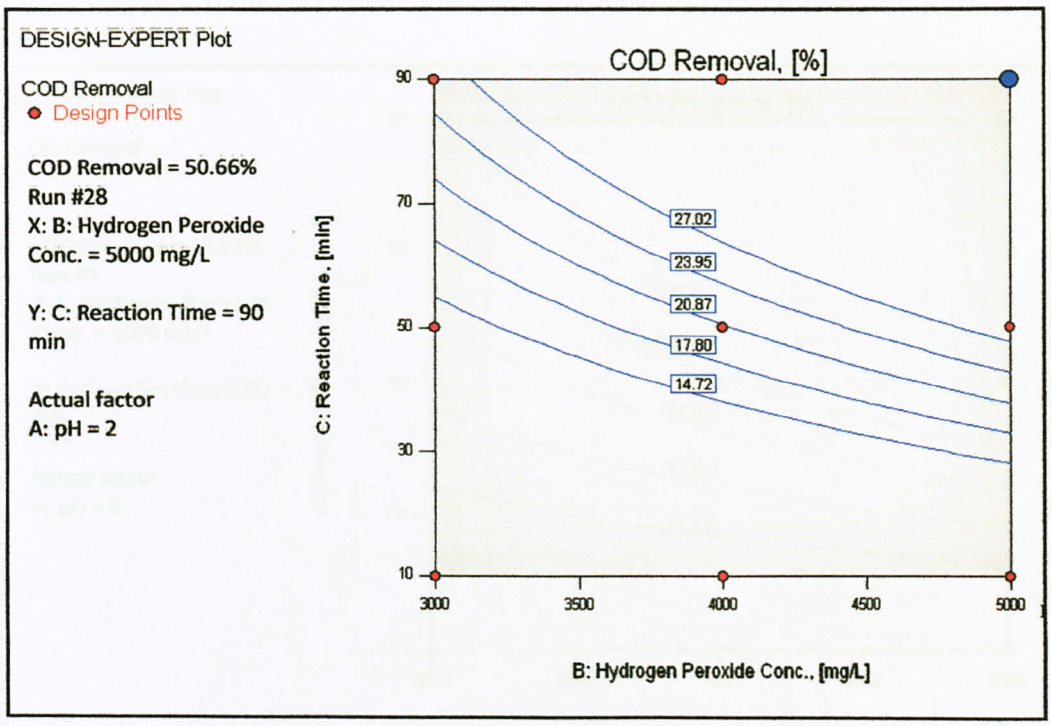

Figure 4.19: Contour plots of COD Removal at pH 2

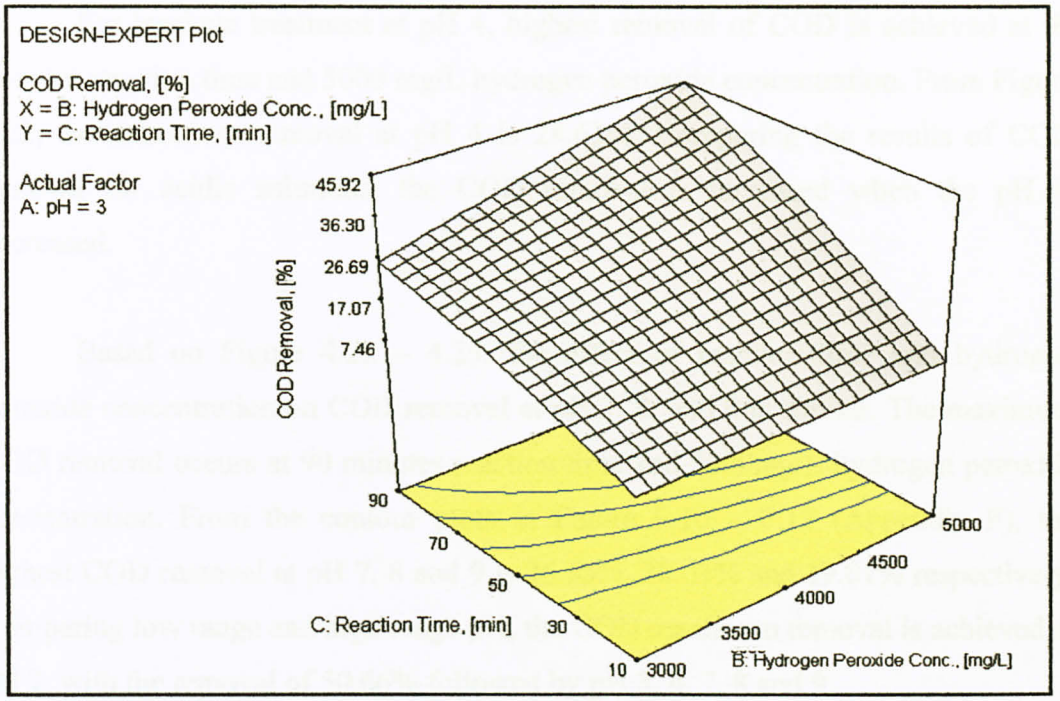

Figure 4.20: 3D Graph of COD Removal at pH 3

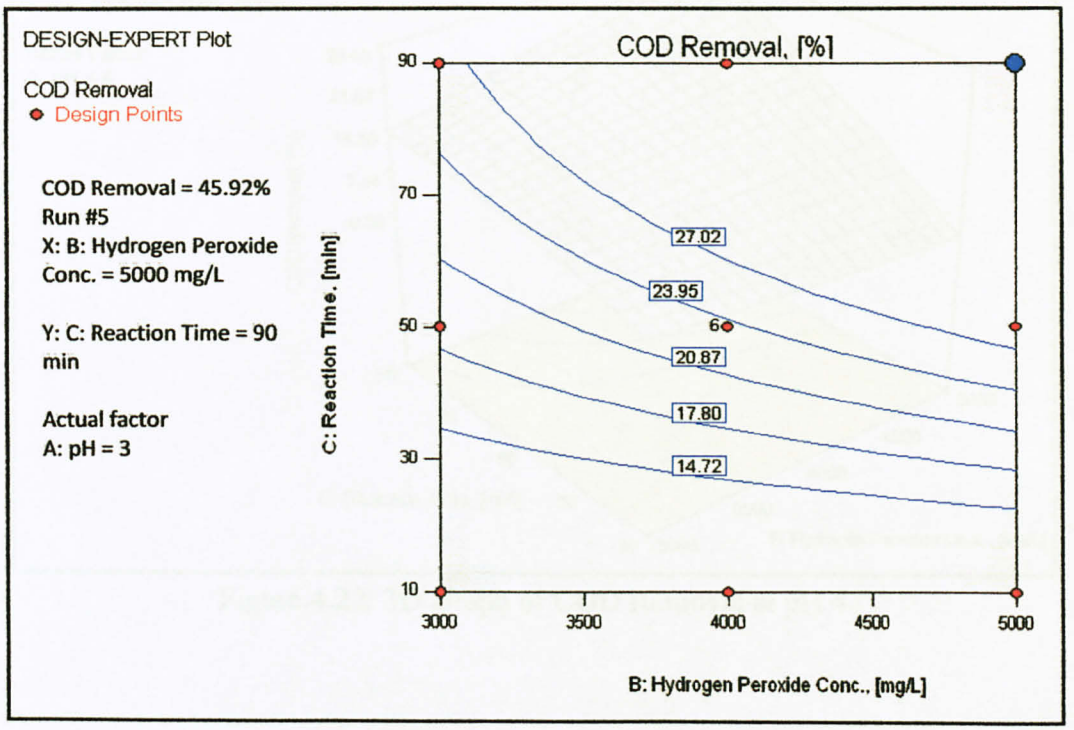

Figure 4.21: Contour plots of COD Removal at pH 3

For leachate treatment at pH 4, highest removal of COD is achieved at 90 minutes reaction time and 5000 mg/L hydrogen peroxide concentration. From Figure 4.22, the maximum removal at pH 4 is 28.63%. Comparing the results of COD removal for acidic solutions, the COD removal is increased when the pH is decreased.

Based on Figure 4.22 – 4.25, the effect of reaction time and hydrogen peroxide concentration on COD removal at pH 7, 8, and 9 is similar. The maximum COD removal occurs at 90 minutes reaction time and 5000mg/L hydrogen peroxide concentration. From the contour plots in Figure F.10 – F.12 (Appendix F), the highest COD removal at pH 7, 8 and 9 is 26.65%, 20.03% and 19.01% respectively. Comparing low range and high range pH, the COD maximum removal is achieved at pH 2, with the removal of 50.66% followed by pH 3, 4, 7, 8 and 9.

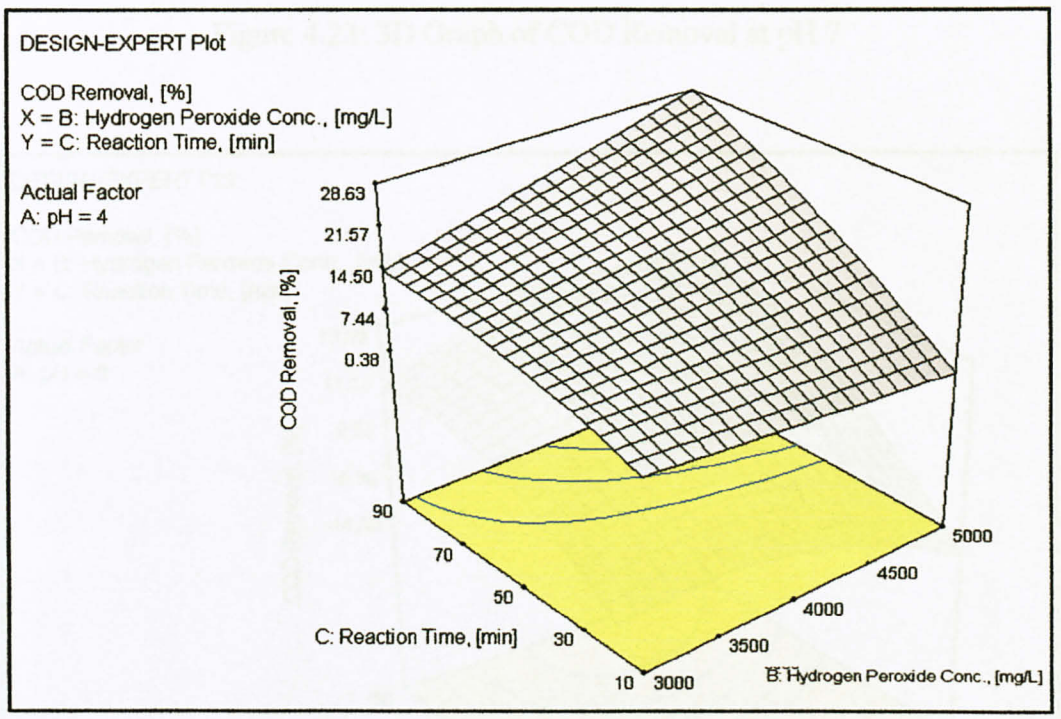

Figure 4.22: 3D Graph of COD Removal at pH 4

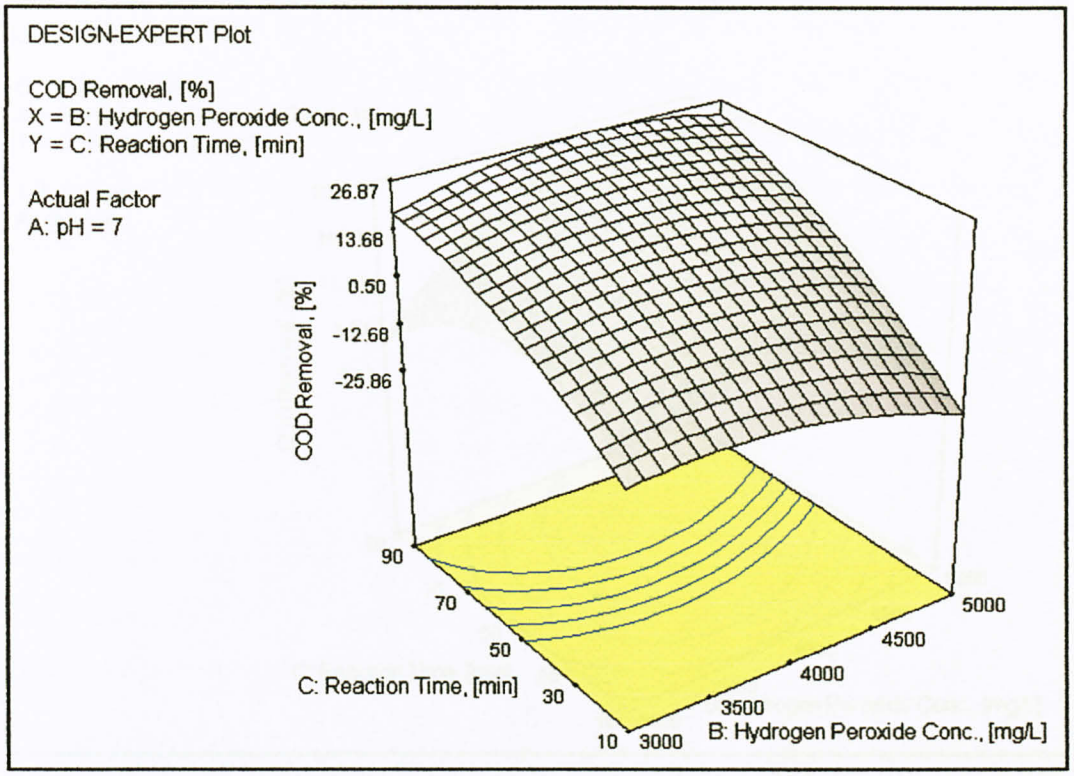

Figure 4.23: 3D Graph of COD Removal at pH 7

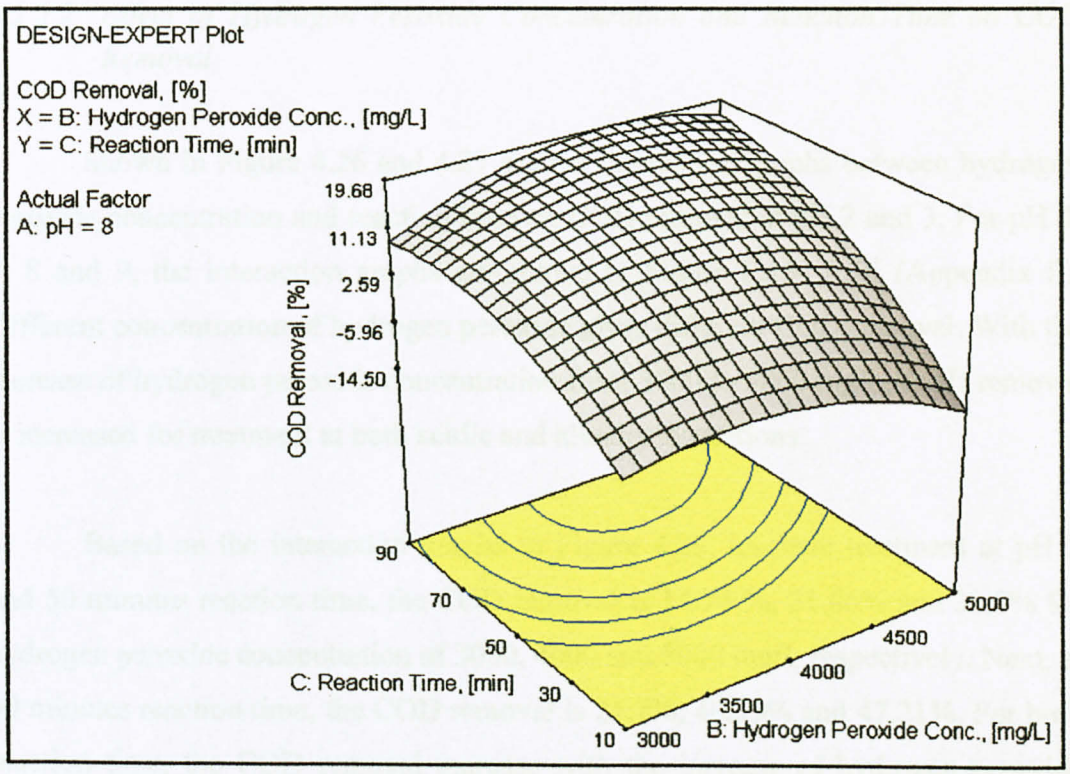

Figure 4.24: 3D Graph of COD Removal at pH 8

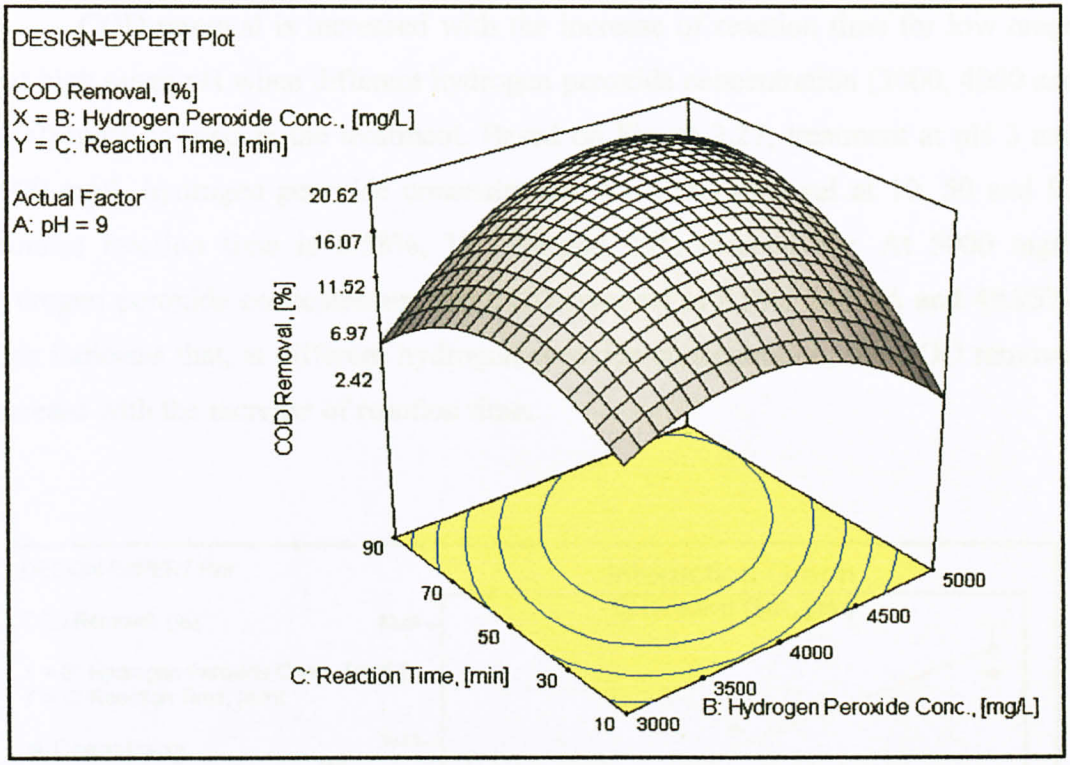

Figure 4.25: 3D Graph of COD Removal at pH 9

4.2.2.2. Effect of Hydrogen Peroxide Concentration and Reaction Time on COD Removal

Shown in Figure 4.26 and 4.27 are the interaction graphs between hydrogen peroxide concentration and reaction time on COD removal at pH 2 and 3. For pH 4, 7, 8 and 9, the interaction graphs are shown in Figure F.13- F.16 (Appendix F). Different concentration of hydrogen peroxide gives different COD removal. With the increase of hydrogen peroxide concentration from 3000 to 5000 mg/L, COD removal is increased for treatment at both acidic and alkaline conditions.

Based on the interaction graphs in Figure 4.26, leachate treatment at pH 2 and 50 minutes reaction time, the COD removal is 14.74 %, 21.86% and 30.9% for hydrogen peroxide concentration of 3000, 4000 and 5000 mg/L respectively. Next, at 90 minutes reaction time, the COD removal is 21.7%, 40.39% and 47.21%. For both reaction time, the COD removal increase with the increase of hydrogen peroxide concentration. This shows that COD removal is directly proportional to hydrogen peroxide concentration.

COD removal is increased with the increase of reaction time for low range and high range pH when different hydrogen peroxide concentration (3000, 4000 and 5000) mg/L is used in the treatment. Based on Figure 2.27, treatment at pH 3 and 3000 mg/L hydrogen peroxide concentration, the COD removal at 10, 50 and 90 minutes reaction time is 6.58%, 18.89% and 26% respectively. At 5000 mg/L hydrogen peroxide concentration, the COD removal is 8.9%, 24.82% and 49.95%. This indicates that, at different hydrogen peroxide concentration, the COD removal increase with the increase of reaction time.

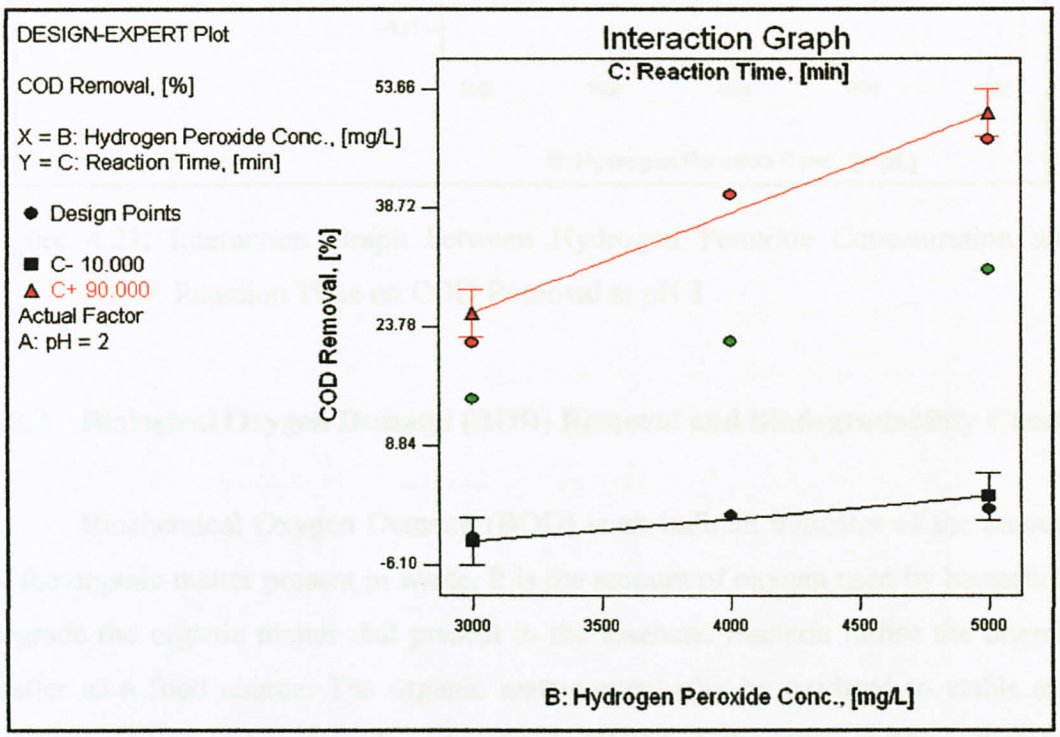

Figure 4.26: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on COD Removal at pH 2

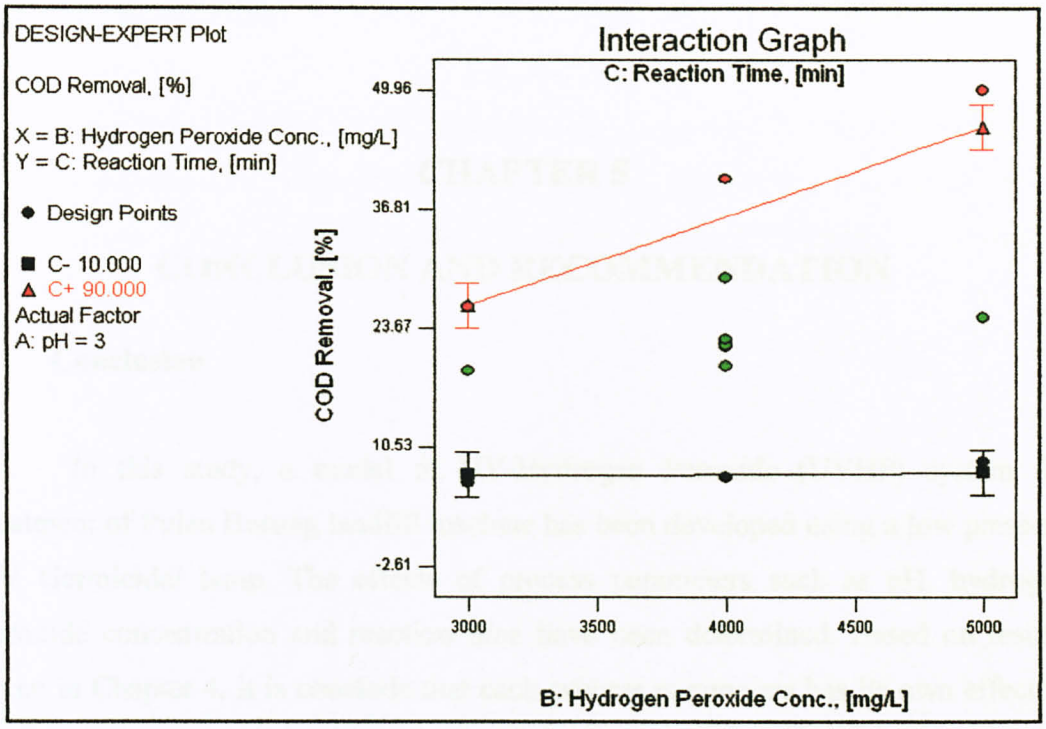

Figure 4.27: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on COD Removal at pH 3

4.2.3 Biological Oxygen Demand (BOD) Removal and Biodegradability Check

Biochemical Oxygen Demand (BOD) is an indirect indicator of the amount of the organic matter present in waste. It is the amount of oxygen used by bacteria to degrade the organic matter that present in the leachate. Bacteria utilise the organic matter as a food source. The organic matter eventually be oxidised to stable end products such as carbon dioxide and water. In BOD test, the initial and final dissolve oxygen (DO) was measured using DO meter. In Appendix D, Table D.13 shows the results for BOD removal and BOD/COD of the leachate after UVHP treatment. Initial BOD_5 of leachate that been measured in the lab is 317 mg/L. The highest BOD removal is obtained at pH 3, 90 minutes reaction time and 5000 mg/L hydrogen peroxide concentration where the BOD removal is 80.3%. From Table D.13, it is shown that the BOD/COD ratio of sample before and after treatment was not much different. Treatment at different pH has results slight reduction and increment in BOD/COD ratio. UV hydrogen peroxide treatment was found to be effective in removing BOD but was not effective in increasing the BOD/COD ratio or enhancing biodegradability of the leachate.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, a model of UV-Hydrogen Peroxide (UVHP) system for treatment of Pulau Burung landfill leachate has been developed using a low pressure UV Germicidal lamp. The effects of process parameters such as pH, hydrogen peroxide concentration and reaction time have been determined. Based on results given in Chapter 4, it is conclude that each process parameters has its own effect to the removal of colour, and chemical oxygen demand (COD) of the leachate.

It was found that increase in pH will reduce the colour and COD removal. In addition, higher hydrogen peroxide concentration promotes a greater removal of colour and COD. Colour and COD removal is also directly proportional to reaction time. Increase in reaction time results in greater removal of colour and COD. As the BOD of treated leachate was measured, it is observed that the BOD has been reduced from 317 mg/L to a minimum of 62.44 mg/L.

UV-Hydrogen Peroxide system was found to be effective in BOD, COD and colour removal but was not effective in increasing the BOD/COD ratio or enhancing biodegradability of the leachate. The maximum removal of colour and COD and BOD is 87.82%, 50.66% and 80.3% respectively.

5.2 Recommendation

For further research in UVHP system, it is suggested to use higher power of Ultraviolet (UV) lamp as the production of hydroxyl radicals is also depends on UV radiation. These may results in higher removal of colour, COD and BOD, as well as increase the biodegradability of the leachate.

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APPENDICES

APPENDIX A

ENVIRONMENTAL QUALITY (SEWAGE AND INDUSTRIAL EFFLUENTS) REGULATIONS, 1979 MAXIMUM EFFLUENT PARAMETERS LIMITS STANDARD A AND B

Parameters		Units	Standard	
			A [1]	B [2]
1	Temperature	°C	40	40
2	pH Value	-	6.0 – 9.0	5.5 – 9.0
3	BOD_5 at 20 °C	mg/L	20	50
4	COD	mg/L	50	100
5	Suspended Solids	mg/L	50	100
6	Mercury	mg/L	0.005	0.05
7	Cadmium	mg/L	0.01	0.02
8	Chromium, Hexalent	mg/L	0.05	0.05
9	Arsenic	mg/L	0.05	0.10
10	Cyanide	mg/L	0.05	0.10
11	Lead	mg/L	0.10	0.5
12	Chromium, Trivalent	mg/L	0.20	1.0
13	Copper	mg/L	0.20	1.0
14	Manganese	mg/L	0.20	1.0
15	Nickel	mg/L	0.20	1.0
16	Tin	mg/L	0.20	1.0
17	Zinc	mg/L	1.0	1.0
18	Boron	mg/L	1.0	4.0
19	Iron (Fe)	mg/L	1.0	5.0
20	Phenol	mg/L	0.001	1.0
21	Free chlorine	mg/L	1.0	2.0
22	Sulphide	mg/L	0.50	0.50
23	Oil and Grease	mg/L	Not detectable	10.0

[1]Standard A for discharge upstream of drinking water take-off

[2]Standard B for inland waters

APPENDIX B

EXPERIMENTAL DESIGN USING DESIGN EXPERT SOFTWARE, RESPONSE SURFACE METHODOLOGY (THREE-LEVEL FACTORIAL)

Table B.1:

Experiment Data Sheet for Colour and Cod (Low Range pH)

Std	Run	Factor 1 A: pH	Factor 2 B: Hydrogen Peroxide Conc. (mg/L)	Factor 3 C: Reaction Time (min)	Response 1 Colour (PtCo)	Response 2 COD (mg/L)
2	1	3	3000	10		
7	2	2	5000	10		
26	3	3	5000	90		
25	4	2	5000	90		
23	5	3	4000	90		
18	6	4	5000	50		
22	7	2	4000	90		
5	8	3	4000	10		
28	9	3	4000	50		
3	10	4	3000	10		
4	11	2	4000	10		
6	12	4	4000	10		
15	13	4	4000	50		
31	14	3	4000	50		
13	15	2	4000	50		
10	16	2	3000	50		
20	17	3	3000	90		
9	18	4	5000	10		
16	19	2	5000	50		
32	20	3	4000	50		
12	21	4	3000	50		
8	22	3	5000	10		
14	23	3	4000	50		
17	24	3	5000	50		
1	25	2	3000	10		
24	26	4	4000	90		
29	27	3	4000	50		
11	28	3	3000	50		
30	29	3	4000	50		
19	30	2	3000	90		
21	31	4	3000	90		
27	32	4	5000	90		

Table B.2:

Experiment Data Sheet for Colour and COD (High Range pH)

Std	Run	Factor 1 A: pH	Factor 2 B: Hydrogen Peroxide Conc. (mg/L)	Factor 3 C: Reaction Time (min)	Response 1 Colour (PtCo)	Response 2 COD (mg/L)
10	1	7	3000	50		
13	2	7	4000	50		
7	3	7	5000	10		
1	4	7	3000	10		
19	5	7	3000	90		
22	6	7	4000	90		
16	7	7	5000	50		
4	8	7	4000	10		
25	9	7	5000	90		
23	10	8	4000	90		
20	11	8	3000	90		
5	12	8	4000	10		
8	13	8	5000	10		
28	14	8	4000	50		
31	15	8	4000	50		
30	16	8	4000	50		
29	17	8	4000	50		
14	18	8	4000	50		
11	19	8	3000	50		
32	20	8	4000	50		
26	21	8	5000	90		
17	22	8	5000	50		
2	23	8	3000	10		
12	24	9	3000	50		
24	25	9	4000	90		
27	26	9	5000	90		
21	27	9	3000	90		
18	28	9	5000	50		
15	29	9	4000	50		
9	30	9	5000	10		
3	31	9	3000	10		
6	32	9	4000	10		

APPENDIX C

SAMPLE CALCULATION

1. Total Suspended solid (TSS)

$$TSS, mg/L = \frac{W_a - W_b}{V}$$

Where,

W	=	*weight of filter paper + pan (mg)*
a	=	*after drying*
b	=	*before drying*
V	=	*sample volume (L)*

2. Total kjeldahl Nitrogen (TKN)

$$\% Nitrogen = \frac{(A-B)\times N\times 1.4}{W} \times 10^{-3} \text{ g N/ml}$$

Where,

A	=	*volume titrated for sample, ml*
B	=	*volume titrated for blank, ml*
N	=	*normality of acid = 0.02*
W	=	*sample weight, mg*

3. Biological Oxygen Demand (BOD) when dilution water is seeded

$$BOD, mg/L = \frac{(D_i - D_f) - (B_i - B_f)f}{P} \times DF$$

where

D_i = dissolved oxygen of diluted sample immediately after preparation, mg/L

D_f = dissolved oxygen of diluted sample after 5-day incubation at 20°C, mg/L

B_i = dissolved oxygen of seed control before incubation, mg/L

B_f = dissolved oxygen of seed control after incubation, mg/L

f = fraction of seeded dilution water volume in sample to volume of seeded dilution water in seed control

P = fraction of wastewater sample volume to total combine volume

DF = Dilution factor

APPENDIX D

RESULTS OF EXPERIMENTS (TABLES)

Table D.1: Table of Result for Turbidity

Date of experiment: 13th April 2009			
Dilution factor	Sample	Turbidity (ntu)	Avg. Turbidity (ntu)
1:10	1	74.0	73.7
	2	72.0	
	3	75.0	
1:16	1	88.0	86.4
	2	86.4	
	3	84.8	
1:20	1	84.0	82.7
	2	80.0	
	3	84.0	
Average turbidity =			81

Table D.2: Table of Result for Colour

Date of experiment: 13th April 2009			
Dilution factor	Sample	Colour (PtCo)	Avg. Colour(PtCo)
1:10	1	4670	4600
	2	4550	
	3	4580	
1:16	1	4620	4680
	2	4690	
	3	4730	
1:20	1	4720	4697
	2	4700	
	3	4670	
Average colour =			4659

Table D.3: Table of Result for Total Suspended Solid (TSS)

Date of experiment: 7th April 2009					
Dilution factor	Sample	Weight of pan + filter disc (mg)		Sample Volume (L)	TSS (mg/L)
		Before	After		
1:1	1	1332.3	1333.9	0.048	33.3
	2	1271.9	1273.8	0.050	38.0
	3	1311.9	1314.0	0.046	45.7
1:2	1	1302.2	1302.6	0.041	39.0
	2	1335.0	1335.5	0.046	43.4
	3	1283.8	1284.3	0.048	41.6
				Average TSS =	40.2

Table D.4: Table of Result for Total Kjeldahl Nitrogen (TKN)

Date of experiment: 13th July 2009			
Sample	Dilution Factor	Titration Volume (mL)	Total Kjeldahl Nitrogen (mg N /L)
Blank 1	-	0.18	-
Blank 2	-	0.115	-
Sample 1	1:1	4.57	2050
Sample 2	1:2	4.26	2115
		Average =	2083

Table D.5: Table of Result for initial Chemical Oxygen Demand (COD) and colour

Dilution factor	Trial No	COD (mg/L)	Colour (PtCo)
1:4	1	3520	4800
	2	3480	4770
	3	3390	4630
1:8	4	3358	4580
	5	3370	4610
	6	3365	4553
1:10	7	3280	4570
	8	3230	4523
	9	3361	4413
Average		3372	4605

Table D.6: Table of initial Chemical Oxygen Demand (COD) and colour after pH adjustment (before UVHP treatment)

pH	COD (mg/L)	Colour (PtCo)
2	2908	4275
3	2907	3853
4	2900	3587
7	3338	4564
8	3387	4565
9	3335	4568

Table D.7: Results of COD and Colour of The Leachate after UVHP Treatment at pH 2

pH	H_2O_2 Conc. (mg/L)	Reaction Time, min	COD				Colour			
			Sample			Removal, %	Sample			Removal, %
			1	2	Avg.		1	2	Avg.	
2	3000	0	2890	2910	2900	14.00	4280	4230	4255	7.62
2	3000	10	3500	3420	3460	-2.61	2180	2140	2160	53.10
2	3000	50	2880	2870	2875	14.74	1950	1960	1955	57.56
2	3000	90	2630	2650	2640	21.71	1180	1160	1170	74.59
2	4000	0	2920	2940	2930	13.11	4260	4290	4275	7.19
2	4000	10	3390	3350	3370	0.06	1870	1880	1875	59.29
2	4000	50	2650	2620	2635	21.86	1130	1100	1115	75.79
2	4000	90	1970	2050	2010	40.39	790	790	790	82.85
2	5000	0	2880	2910	2895	14.15	4220	4370	4295	6.75
2	5000	10	3370	3310	3340	0.95	1700	1730	1715	62.76
2	5000	50	2300	2360	2330	30.90	1120	1130	1125	75.58
2	5000	90	1770	1790	1780	47.21	740	750	745	83.83

Table D.8: Results of COD and colour of the leachate after UVHP treatment at pH 3

pH	H_2O_2 Conc. (mg/L)	Reaction Time, min	COD				Colour			
			Sample			Removal, %	Sample			Removal, %
			1	2	Avg.		1	2	Avg.	
3	3000	0	2920	2980	2950	12.51	3940	3910	3925	14.79
3	3000	10	3140	3160	3150	6.58	2150	2070	2110	54.19
3	3000	50	2720	2750	2735	18.89	1910	1920	1915	58.42
3	3000	90	2480	2510	2495	26.01	1490	1540	1515	67.11
3	4000	0	2870	2920	2895	14.15	3980	3840	3910	15.11
3	4000	10	3150	3110	3130	7.18	2470	1950	2210	52.02
3	4000	50	2680	2610	2645	21.56	840	790	815	82.31
3	4000	90	2100	1935	2018	40.17	610	540	575	87.52
3	5000	0	2840	2910	2875	14.74	3640	3810	3725	19.13
3	5000	10	3010	3130	3070	8.96	1360	1740	1550	66.35
3	5000	50	2530	2540	2535	24.82	830	1390	1110	75.90
3	5000	90	1750	1625	1688	49.96	580	430	505	89.04

Table D.9: Results of COD and colour of the leachate after UVHP treatment at pH 4

pH	H_2O_2 Conc. (mg/L)	Reaction Time, min	COD				Colour			
			Sample			Removal, %	Sample			Removal, %
			1	2	Avg.		1	2	Avg.	
4	3000	0	2880	2930	2905	13.85	3550	3600	3575	22.38385
4	3000	10	3190	3220	3205	4.95	3130	3110	3120	32.26227
4	3000	50	2910	2930	2920	13.40	2290	2270	2280	50.49935
4	3000	90	2875	2850	2862.5	15.11	2600	2580	2590	43.769
4	4000	0	2910	2890	2900	14.00	3610	3580	3595	21.94963
4	4000	10	3310	3270	3290	2.43	3190	3150	3170	31.17673
4	4000	50	2910	2880	2895	14.15	3070	3040	3055	33.67347
4	4000	90	2750	2765	2757.5	18.22	2900	2890	2895	37.1472
4	5000	0	2900	2890	2895	14.15	3570	3610	3590	22.05818
4	5000	10	3290	3320	3305	1.99	3150	3130	3140	31.82805
4	5000	50	2810	2780	2795	17.11	2970	2940	2955	35.84455
4	5000	90	2400	2500	2450	27.34	2270	2250	2260	50.93356

Table D.10: Results of COD and colour of the leachate after UVHP treatment at pH 7

pH	H_2O_2 Conc. (mg/L)	Reaction Time, min	COD				Colour			
			Sample			Removal, %	Sample			Removal, %
			1	2	Avg.		1	2	Avg.	
7	3000	0	3440	3390	3415	-2.15	4590	4610	4600	0.13
7	3000	10	4340	4290	4315	-29.08	3270	3290	3280	28.79
7	3000	50	2860	2910	2885	13.70	1520	1560	1540	66.57
7	3000	90	2770	2830	2965	11.31	1390	1370	1380	70.04
7	4000	0	3190	3180	3185	4.73	4510	4500	4505	2.19
7	4000	10	3310	3320	3315	0.84	1940	1960	1950	57.66
7	4000	50	2750	2790	2770	17.14	1120	1110	1115	75.79
7	4000	90	2730	2680	2705	19.08	790	780	785	82.96
7	5000	0	3440	3390	3415	-2.15	4550	4620	4585	0.46
7	5000	10	4540	4480	4510	-34.91	2640	2640	2640	42.68
7	5000	50	2770	2810	2790	16.54	1660	1630	1645	64.29
7	5000	90	2630	2650	2640	21.03	730	750	740	83.93

Table D.11: Results of COD and colour of the leachate after UVHP treatment at pH 8

pH	H_2O_2 Conc. (mg/L)	Reaction Time, min	COD				Colour			
			Sample			Removal, %	Sample			Removal, %
			1	2	Avg.		1	2	Avg.	
8	3000	0	3250	3310	3280	1.88	4500	4520	4510	2.08
8	3000	10	3330	3320	3325	0.54	1720	1730	1725	62.55
8	3000	50	3020	3020	3020	9.66	1300	1330	1315	71.45
8	3000	90	2950	2940	2945	11.91	1160	1180	1170	74.60
8	4000	0	3520	3650	3585	-7.24	4600	4590	4595	0.24
8	4000	10	2870	3030	2950	11.76	2690	2700	2695	41.49
8	4000	50	2950	2920	2935	12.20	2660	2660	2660	42.25
8	4000	90	2760	2740	2750	17.74	2370	2350	2360	48.76
8	5000	0	3250	3340	3295	1.44	4570	4610	4590	0.35
8	5000	10	4400	4290	4345	-29.97	2800	2780	2790	39.43
8	5000	50	3280	3350	3315	0.84	2040	2060	2050	55.49
8	5000	90	2620	2650	2635	21.18	1820	1830	1825	60.38

Table D.12: Results of COD and colour of the leachate after UVHP treatment at pH 9

pH	H_2O_2 Conc. (mg/L)	Reaction Time, min	COD				Colour			
			Sample			Removal, %	Sample			Removal, %
			1	2	Avg.		1	2	Avg.	
9	3000	0	3310	3360	3335	0.24	4570	4560	4565	0.89
9	3000	10	3120	3110	3115	6.82	2670	2670	2670	42.03
9	3000	50	3030	3030	3030	9.36	2590	2580	2585	43.88
9	3000	90	2970	2960	2965	11.31	2500	2490	2495	45.83
9	4000	0	3350	3330	3340	0.09	4550	4570	4560	1.00
9	4000	10	3080	3090	3085	7.72	2750	2760	2755	40.19
9	4000	50	2990	3000	2995	10.41	2530	2550	2540	44.85
9	4000	90	2910	2930	2920	12.65	2440	2450	2445	46.92
9	5000	0	3340	3320	3330	0.39	4580	4570	4575	0.67
9	5000	10	2910	2900	2905	13.10	2550	2530	2540	44.85
9	5000	50	2760	2760	2760	17.44	1870	1880	1875	59.29
9	5000	90	2690	2680	2685	19.68	1760	1780	1770	61.57

Table D.13: Summary of results for BOD_5 and BOD_5/COD of the leachate after UVHP treatment at 90 minutes reaction time

Date	pH	H_2O_2 Conc. (mg/L)	BOD, (mg/L)	BOD Removal, (%)	BOD_5 /COD
05/10/2009	2	3000	222.27	29.88	0.084
06/10/2009	2	4000	157.69	50.26	0.078
02/09/2009	2	5000	97.97	69.09	0.055
06/10/2009	3	3000	138.66	56.26	0.056
06/10/2009	3	4000	79.61	74.89	0.039
15/09/2009	3	5000	62.44	80.30	0.037
05/09/2009	4	3000	233.37	26.38	0.082
02/09/2009	4	4000	204.15	35.60	0.074
05/10/2009	4	5000	158.07	50.14	0.065
15/09/2009	7	3000	258.74	18.38	0.092
05/10/2009	7	4000	216.09	31.83	0.080
15/09/2009	7	5000	246.39	22.27	0.093
05/10/2009	8	3000	255.59	18.43	0.094
02/09/2009	8	4000	221.43	30.15	0.075
06/10/2009	8	5000	213.74	32.57	0.081
05/10/2009	9	3000	244.49	6.61	0.101
15/09/2009	9	4000	252.56	19.39	0.086
15/09/2009	9	5000	231.58	23.25	0.091

Table D.14: Data for BOD_5 test 1

Day 1: 14th August 2009

Day 5: 19th August 2009

Sample volume	= 8 ml	B	= Blank
Seed volume	= 1 ml	S	= Seed Correction
Total volume	= 300ml	DO	= Dissolved Oxygen

Sample	Hydrogen Peroxide Conc. (mg/L)	DO(i) (mg/L)	DO(f) (mg/L)	DO(i)-DO(f) (mg/L)	Avg. Δ DO	BOD_5 (mg/L)
B	N/A	8.96	8.77	0.19		N/A
B		8.97	8.74	0.23		
B		8.95	8.76	0.19	0.203	
S		8.90	8.34	0.56		
S		8.70	8.29	0.41		
S		8.80	8.31	0.49	0.487	
Treated Sample						
pH 4	4000	9.17	8.06	1.11		235.611
pH 4	4000	9.14	7.95	1.19		265.240
pH 4	4000	9.07	8.03	1.04		209.685
					1.113	236.845
pH 8	4000	9.06	7.93	1.13		243.018
pH 8	4000	9.06	7.98	1.08		224.500
pH 8	4000	9.01	7.92	1.09		228.203
					1.100	231.907

Table D.15: Data for BOD_5 test 2

Day 1: 28th August 2009

Day 5: 2nd September 2009

Sample volume	= 8 ml	B	= Blank
Seed volume	= 1 ml	S	= Seed Correction
Total volume	= 300ml	L	= Leachate before treatment

Sample	Hydrogen Peroxide Conc. (mg/L)	DO(i) (mg/L)	DO(f) (mg/L)	DO(i)-DO(f) (mg/L)	Avg. Δ DO	BOD_5 (mg/L)
B	N/A	8.73	8.47	0.26		N/A
B		8.71	8.54	0.17		
B		8.74	8.46	0.28	0.237	
S		8.74	8.34	0.40		
S		8.74	8.29	0.45		
S		8.74	8.31	0.43	0.427	
L		8.68	7.44	1.24		305.381
L		8.68	7.39	1.29		323.900
L		8.67	7.41	1.26		312.789
					1.263	314.023
Treated Sample						
pH 2	5000	8.69	8.02	0.67		94.270
pH 2	5000	8.70	7.98	0.72		112.789
pH 2	5000	8.68	8.03	0.65		86.863
					0.680	97.974
pH 3	4000	8.93	8.33	0.60		68.344
pH 3	4000	9.03	8.43	0.60		68.344
pH 3	4000	8.97	8.35	0.62		75.751
					0.607	70.813
pH 4	4000	8.76	7.86	0.90		179.455
pH 4	4000	8.74	7.70	1.04		231.307
pH 4	4000	8.76	7.80	0.96		201.677
					0.967	204.147
pH 8	4000	8.65	7.61	1.04		231.307
pH 8	4000	8.68	7.69	0.99		212.789
pH 8	4000	8.66	7.65	1.01		220.196
					1.013	221.430

Table D.16: Data for BOD_5 test 3

Day 1: 10th September 2009

Day 5: 15th September 2009

Sample volume	= 8 ml	B	= Blank
Seed volume	= 1 ml	S	= Seed Correction
Total volume	= 300ml	L	= Leachate before treatment

Sample	Hydrogen Peroxide Conc. (mg/L)	DO(i) (mg/L)	DO(f) (mg/L)	DO(i)-DO(f) (mg/L)	Avg. Δ DO	BOD_5 (mg/L)
B	N/A	8.53	8.27	0.26		N/A
B		8.54	8.34	0.20		
B		8.53	8.49	0.04	0.167	
S		8.53	8.30	0.23		
S		8.50	8.29	0.21		
S		8.49	8.31	0.18	0.207	
L		8.47	7.47	1.00		295.774
L		8.49	7.43	1.06		317.996
L		8.47	7.38	1.09		329.107
					1.050	314.292
Treated Sample						
pH 3	5000	8.61	8.21	0.40		73.551
pH 3	5000	8.60	8.25	0.35		55.033
pH 3	5000	8.63	8.27	0.36		58.737
					0.370	62.440
pH 7	3000	8.50	7.63	0.87		247.626
pH 7	3000	8.47	7.59	0.88		251.329
pH 7	3000	8.49	7.54	0.95		277.255
					0.900	258.737
pH 7	5000	8.43	7.51	0.92		266.144
pH 7	5000	8.46	7.59	0.87		247.626
pH 7	5000	8.43	7.62	0.81		225.403
					0.867	246.391
pH 9	4000	8.45	7.51	0.94		273.551
pH 9	4000	8.50	7.57	0.93		269.848
pH 9	4000	8.48	7.70	0.78		214.292
					0.883	252.564
pH 9	5000	8.42	7.59	0.83		232.811
pH 9	5000	8.42	7.50	0.92		266.144
pH 9	5000	8.38	7.65	0.73		195.774
					0.827	231.576

Table D.17: Data for BOD_5 test 4

Day 1: 30th September 2009

Day 5: 5th October 2009

Sample volume	= 8 ml	B	= Blank
Seed volume	= 1 ml	S	= Seed Correction
Total volume	= 300ml		

Sample	Hydrogen Peroxide Conc. (mg/L)	DO(i) (mg/L)	DO(f) (mg/L)	DO(i)-DO(f) (mg/L)	Avg. Δ DO	BOD_5 (mg/L)
B	N/A	8.86	8.63	0.23		N/A
B		8.86	8.67	0.19		
B		8.85	8.65	0.2	0.207	
S		8.81	8.44	0.37		
S		8.76	8.36	0.4		
S		8.78	8.39	0.39	0.387	
Treated Sample						
pH 2	3000	8.83	7.83	1		230.907
pH 2	3000	8.83	7.85	0.98		223.500
pH 2	3000	8.83	7.88	0.95		212.389
					0.977	222.265
pH 2	4000	8.74	7.86	0.88		186.463
pH 2	4000	8.75	7.87	0.88		186.463
pH 2	4000	8.75	7.95	0.8		156.833
					0.853	176.586
pH 3	4000	8.83	8.21	0.62		90.166
pH 3	4000	8.79	8.18	0.61		86.463
pH 3	4000	8.76	8.24	0.52		53.129
					0.583	76.586
pH 4	3000	8.69	7.62	1.07		256.833
pH 4	3000	8.69	7.73	0.96		216.092
pH 4	3000	8.68	7.69	0.99		227.203
					1.01	233.376
pH 4	5000	8.70	7.95	0.75		138.314
pH 4	5000	8.68	7.90	0.78		149.426
pH 4	5000	8.72	7.84	0.88		186.463
					0.803	158.068
pH 7	4000	8.67	7.73	0.94		208.685
pH 7	4000	8.66	7.65	1.01		234.611
pH 7	4000	8.65	7.72	0.93		204.981
					0.960	216.092

Sample	Hydrogen Peroxide Conc. (mg/L)	DO(i) (mg/L)	DO(f) (mg/L)	DO(i)-DO(f) (mg/L)	Avg. Δ DO	BOD_5 (mg/L)
pH 8	3000	8.61	7.54	1.07		256.833
pH 8	3000	8.65	7.55	1.1		267.944
pH 8	3000	8.59	7.56	1.03		242.018
					1.067	255.598
pH 9	3000	8.59	7.54	1.05		249.426
pH 9	3000	8.59	7.55	1.04		245.722
pH 9	3000	8.58	7.56	1.02		238.314
					1.037	244.487

Table D.18: Data for BOD_5 test 5

Day 1: 1st October 2009

Day 5: 6th October 2009

Sample volume	= 10 ml	B	= Blank
Seed volume	= 1 ml	S	= Seed Correction
Total volume	= 300ml	L	= Leachate before treatment

Sample	Hydrogen Peroxide Conc. (mg/L)	DO(i) (mg/L)	DO(f) (mg/L)	DO(i)-DO(f) (mg/L)	Avg. Δ DO	BOD_5 (mg/L)
B	N/A	9.26	9.12	0.14		N/A
B		9.23	9.10	0.13		
B		9.28	9.13	0.15	0.140	
S		9.30	9.15	0.15		
S		9.28	9.15	0.13		
S		9.28	9.10	0.18	0.153	
L		9.23	8.02	1.21		318.847
L		9.24	7.98	1.26		333.862
L		9.24	8.06	1.18		309.838
					1.217	320.849
Treated Sample						
pH 2	4000	9.35	8.63	0.72		171.699
pH 2	4000	9.35	8.75	0.60		135.663
pH 2	4000	9.38	8.68	0.70		165.693
					0.673	157.685
pH 3	3000	9.33	8.76	0.57		126.654
pH 3	3000	9.35	8.67	0.68		159.687
pH 3	3000	9.33	8.75	0.58		129.657
					0.610	138.666
pH 3	4000	9.39	9.01	0.38		69.597
pH 3	4000	9.35	8.88	0.47		96.624
pH 3	4000	9.33	8.94	0.39		72.600
					0.413	79.607
pH 8	5000	9.20	8.35	0.85		210.738
pH 8	5000	9.25	8.38	0.87		216.744
pH 8	5000	9.19	8.33	0.86		213.741
					0.860	213.741

APPENDIX E

RESULTS OF EXPERIMENTS

(STATISTICAL ANALYSIS)

E.1 Statistical Analysis for Low pH Range

Colour Removal

Table E.1.1: Sequential Model Sum of Squares for Colour Removal

Sequential Model Sum of Squares						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	127090.190	1	127090.1896			
Linear	6652.524	3	2217.507913	13.65368	< 0.0001	
2FI	152.835	3	50.94510851	0.289812	0.8323	
Quadratic	3629.785	3	1209.928272	34.80045	< 0.0001	Suggested
Cubic	236.019	7	33.71697077	0.956295	0.4951	Aliased
Residual	528.869	15	35.25790024			
Total	138290.221	32	4321.569399			

Table E.1.2: Model Summary Statistics for Colour Removal

Model Summary Statistics						
Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	12.744	0.594	0.550	0.501	5594.302	
2FI	13.258	0.608	0.513	0.380	6947.016	
Quadratic	5.896	0.932	0.904	0.860	1572.643	Suggested
Cubic	5.938	0.953	0.902	0.678	3605.75	Aliased

Table E.1.3: Analysis of Variance Table for Colour Removal

Analysis of Variance Table [Partial sum of squares]						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	10435.144	9	1159.460	33.349	< 0.0001	significant
A	4307.193	1	4307.193	123.885	< 0.0001	
B	446.663	1	446.663	12.847	0.0017	
C	1898.668	1	1898.668	54.610	< 0.0001	
A^2	2497.698	1	2497.698	71.840	< 0.0001	
B^2	178.089	1	178.089	5.122	0.0338	
C^2	63.578	1	63.578	1.829	0.1900	
AB	106.293	1	106.293	3.057	0.0943	
AC	28.380	1	28.380	0.816	0.3761	
BC	18.163	1	18.163	0.522	0.4774	

Table E.1.4: Estimate Coefficient for Colour Removal

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	78.014	1	1.981	73.91	82.12	
A-pH	-15.469	1	1.390	-18.35	-12.59	1
B-Hydrogen Peroxide Conc., [mg/L]	4.981	1	1.390	2.10	7.86	1
C-Reaction Time, [min]	10.270	1	1.390	7.39	13.15	1
A^2	-18.685	1	2.205	-23.26	-14.11	1.101
B^2	-4.989	1	2.205	-9.56	-0.42	1.101
C^2	-2.981	1	2.205	-7.55	1.59	1.101
AB	-2.976	1	1.702	-6.51	0.55	1
AC	-1.538	1	1.702	-5.07	1.99	1
BC	1.230	1	1.702	-2.30	4.76	1

Final Equation in Terms of Coded Factors:

$$\text{Colour Removal, [\%]} = 78.01 - 15.47A + 4.98B + 10.27C - 18.69A^2 - 4.99B^2 - 2.98C^2 - 2.98AB - 1.54AC + 1.23BC$$

COD Removal

Table E.1.5: Sequential Model Sum of Squares for COD Removal

Sequential Model Sum of Squares						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	11587.714	1	11587.71			
Linear	4288.357	3	1429.45	32.78875	< 0.0001	
2FI	670.100	3	223.36	10.14229	0.0001	
Quadratic	375.687	3	125.22	15.75248	< 0.0001	Suggested
Cubic	47.413	7	6.77	0.796972	0.6017	Aliased
Residual	127.482	15	8.49			
Total	17096.753	32	534.27			

Table E.1.6: Model Summary Statistics for COD Removal

Model Summary Statistics						
Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	6.603	0.778	0.755	0.689	1714.52	
2FI	4.693	0.900	0.876	0.801	1096.08	
Quadratic	2.819	0.968	0.955	0.932	373.89	Suggested
Cubic	2.915	0.977	0.952	0.881	656.81	Aliased

Table E.1.7: Analysis of variance table [Partial sum of squares] for COD Removal

Analysis of variance table [Partial sum of squares]						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	5334.144	9	592.68	74.55	< 0.0001	significant
A	203.335	1	203.33	25.56	< 0.0001	
B	454.519	1	454.52	57.17	< 0.0001	
C	3630.503	1	3630.50	456.68	< 0.0001	
A^2	281.022	1	281.02	35.35	< 0.0001	
B^2	0.050	1	0.05	0.01	0.9374	
C^2	23.675	1	23.67	2.98	0.0984	
AB	86.677	1	86.67	10.90	0.0032	
AC	296.098	1	296.09	37.25	< 0.0001	
BC	287.325	1	287.33	36.14	< 0.0001	
Residual	174.896	22	7.95			

Table E.1.8: Coefficient Estimate for COD Removal

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	23.531	1	0.947	21.566	25.496	
A: pH	-3.361	1	0.665	-4.739	-1.983	1
B: Hydrogen Peroxide Conc., [mg/L]	5.025	1	0.665	3.647	6.403	1
C: Reaction Time, [min]	14.202	1	0.665	12.824	15.580	1
A^2	-6.268	1	1.054	-8.454	-4.081	1.101
B^2	0.084	1	1.054	-2.102	2.270	1.101
C^2	-1.819	1	1.054	-4.005	0.367	1.101
AB	-2.688	1	0.814	-4.376	-1.000	1
AC	-4.967	1	0.814	-6.655	-3.279	1
BC	4.893	1	0.814	3.205	6.581	1

Final Equation in Terms of Coded Factors:

$$\text{COD Removal, [\%]} = 23.53 - 3.36A + 5.03B + 14.2C - 6.27A^2 + 0.08B^2 - 1.82C^2 - 2.69AB - 4.97AC + 4.89BC$$

E.2 Statistical Analysis for High pH Range

Colour Removal

Table E.2.1: Sequential Model Sum of Squares for Colour Removal

Sequential Model Sum of Squares						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	91353.501	1	91353.501			
Linear	2850.331	3	950.110	7.553	0.0007	Suggested
2FI	586.301	3	195.434	1.664	0.2002	
Quadratic	499.916	3	166.639	1.505	0.2410	
Cubic	1333.192	7	190.456	2.590	0.0577	Aliased
Residual	1102.997	15	73.533			
Total	97726.237	32	3053.945			

Table E.2.2: Model Summary Statistics for Colour Removal

Model Summary Statistics						
Source	Std.Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	11.216	0.447	0.388	0.272	4639.029	Suggested
2FI	10.837	0.539	0.429	0.228	4917.197	
Quadratic	10.523	0.618	0.461	0.039	6122.173	
Cubic	8.575	0.827	0.642	-0.414	9011.433	Aliased

Table E.2.3: Analysis of variance table for Colour Removal

Analysis of variance table [Partial sum of squares]						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	3436.631	6	572.77	4.876	0.0020	significant
A	1140.689	1	1140.69	9.712	0.0046	
B	2.127	1	2.12	0.018	0.8940	
C	1707.514	1	1707.51	14.538	0.0008	
AB	5.974	1	5.97	0.050	0.8234	
AC	540.653	1	540.65	4.603	0.0418	
BC	39.673	1	39.67	0.337	0.5663	
Residual	2936.104	25	117.44			

Table E.2.4: Coefficient Estimate for Colour Removal

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	23.531	1	0.947	21.566	25.496	
A-pH	-3.361	1	0.665	-4.739	-1.983	1
B-Hydrogen Peroxide Conc., [mg/L]	5.025	1	0.665	3.647	6.403	1
C-Reaction Time, [min]	14.202	1	0.665	12.824	15.580	1
A^2	-6.268	1	1.054	-8.454	-4.081	1.101
B^2	0.084	1	1.054	-2.102	2.270	1.101
C^2	-1.819	1	1.054	-4.005	0.367	1.101
AB	-2.688	1	0.814	-4.376	-1.000	1
AC	-4.967	1	0.814	-6.655	-3.279	1
BC	4.893	1	0.814	3.205	6.581	1

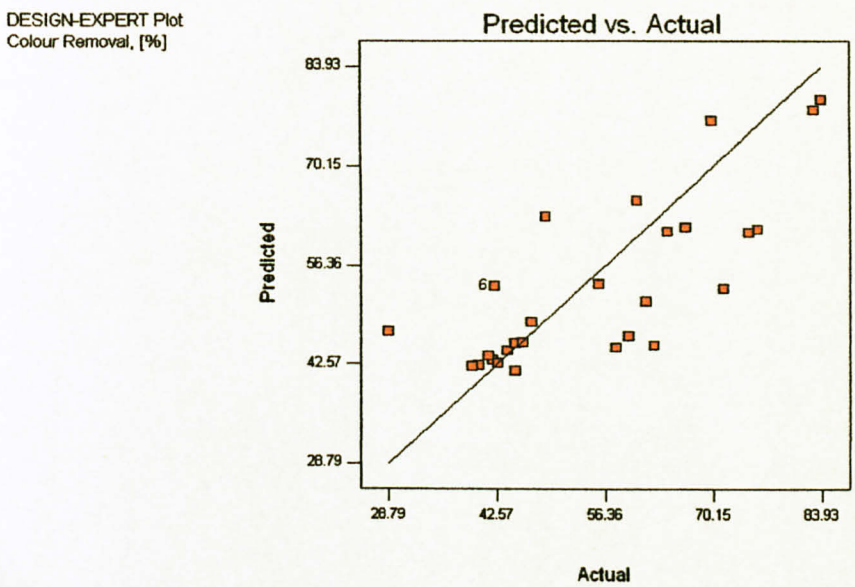

Figure E.1: Predicted vs. Actual for Colour Removal at High pH Range

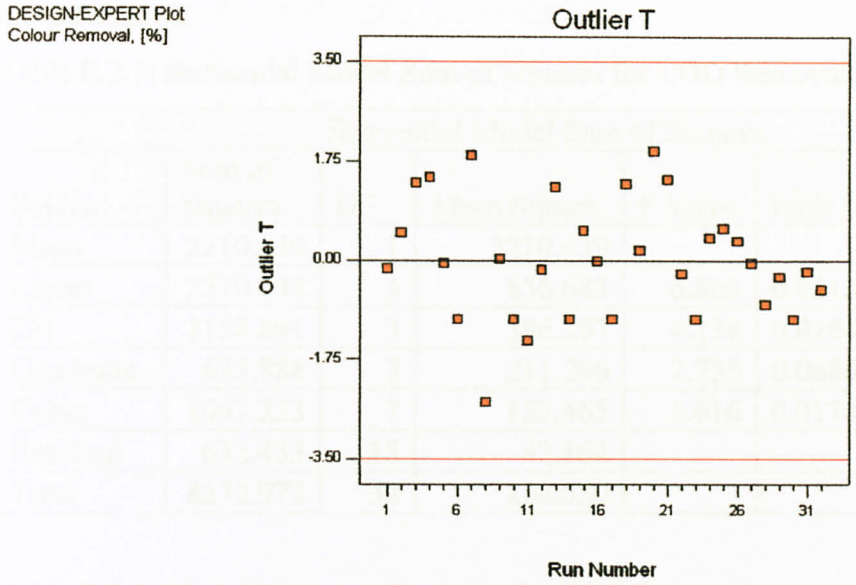

Figure E.2: Outlier T vs. Run Order for Colour Removal at High pH Range

COD Removal

Table E.2.5: Sequential Model Sum of Squares for COD Removal

Sequential Model Sum of Squares						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	2210.439	1	2210.439			
Linear	2570.048	3	856.683	6.868	0.0013	
2FI	1158.891	3	386.297	4.138	0.0164	Suggested
Quadratic	633.888	3	211.296	2.735	0.0680	
Cubic	1067.253	7	152.465	3.616	0.0174	Aliased
Residual	632.453	15	42.164			
Total	8272.972	32	258.530			

Table E.2.6: Model Summary Statistics for COD Removal

Model Summary Statistics						
Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	11.168	0.424	0.362	0.179	4977.419	
2FI	9.661	0.615	0.523	0.208	4800.017	Suggested
Quadratic	8.790	0.720	0.605	0.263	4470.338	
Cubic	6.493	0.896	0.784	0.030	5878.765	Aliased

Table E.2.7: Analysis of variance table for COD Removal

Analysis of variance table [Partial sum of squares]						
Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	3728.939	6	621.490	6.658	0.0003	significant
A	256.157	1	256.157	2.744	0.1101	
B	1.701	1	1.701	0.018	0.8937	
C	2312.190	1	2312.190	24.771	< 0.0001	
AB	36.538	1	36.538	0.391	0.5372	
AC	892.685	1	892.685	9.563	0.0048	
BC	229.668	1	229.668	2.460	0.1293	
Residual	2333.594	25	93.344			

Table E.2.8: Coefficient Estimate for COD Removal

Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF
Intercept	8.311	1	1.708	4.794	11.829	
A-pH	3.772	1	2.277	-0.918	8.462	1
B-Hydrogen Peroxide Conc., [mg/L]	-0.307	1	2.277	-4.997	4.383	1
C-Reaction Time, [min]	11.334	1	2.277	6.644	16.024	1
AB	1.745	1	2.789	-3.999	7.489	1
AC	-8.625	1	2.789	-14.369	-2.881	1
BC	4.375	1	2.789	-1.369	10.119	1

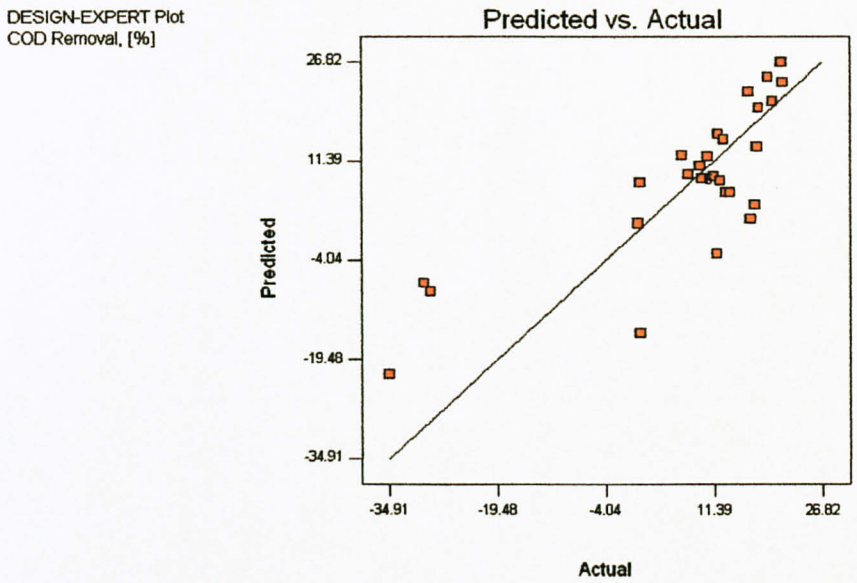

Figure E.3: Predicted vs. Actual for COD Removal at High pH Range

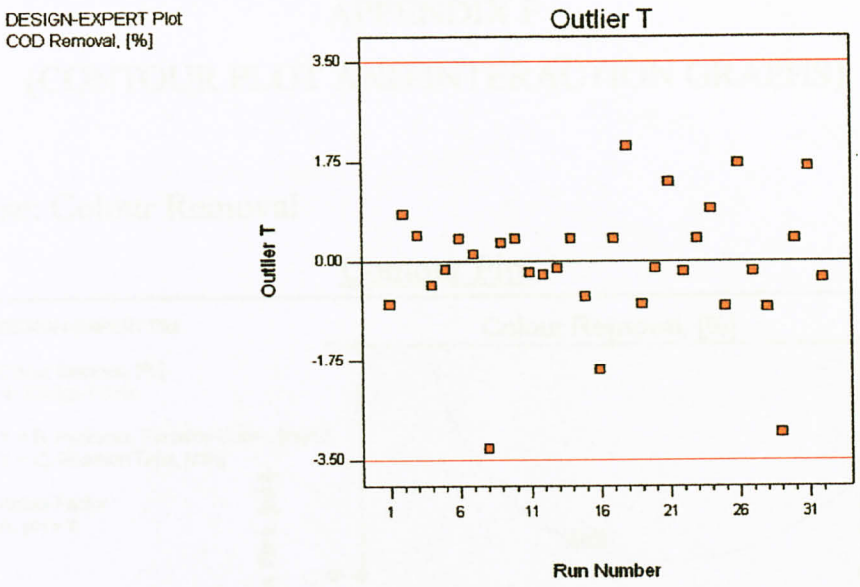

Figure E.4: Outlier T vs. Run Order for COD Removal at High pH Range

APPENDIX F

(CONTOUR PLOT AND INTERACTION GRAPHS)

Response: Colour Removal

Contour Plot

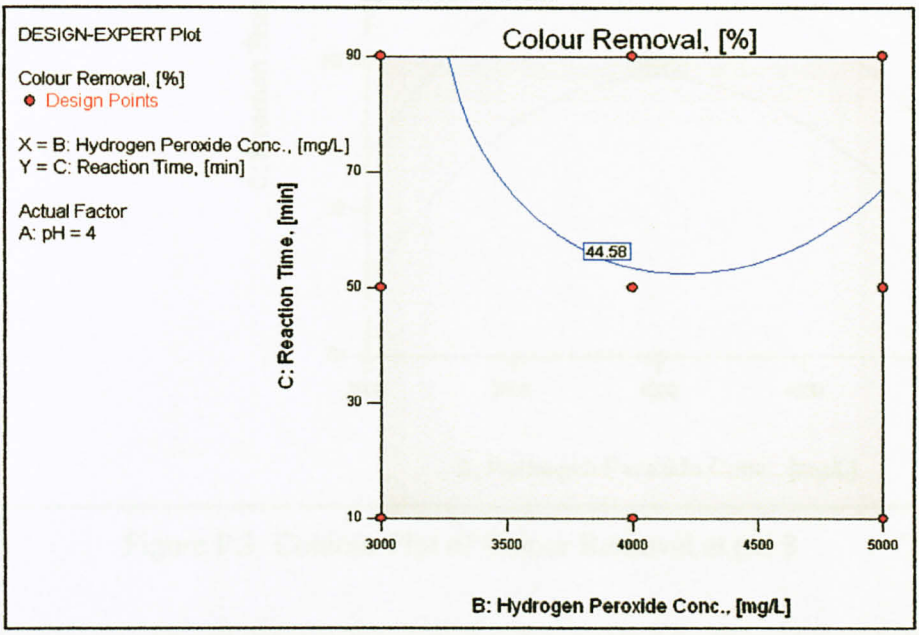

Figure F.1: Contour Plot of Colour Removal at pH 4

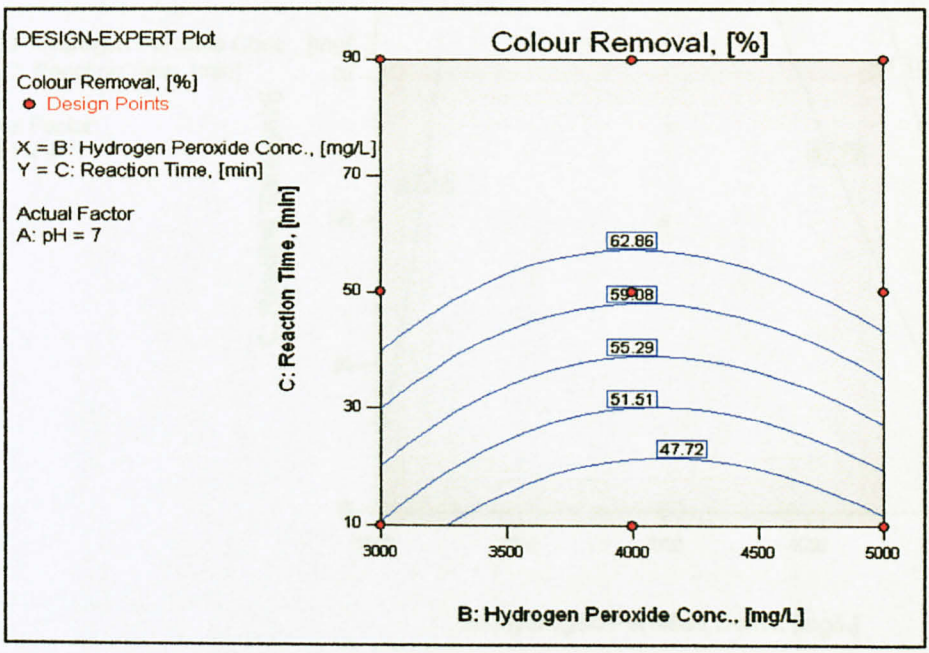

Figure F.2: Contour Plot of Colour Removal at pH 7

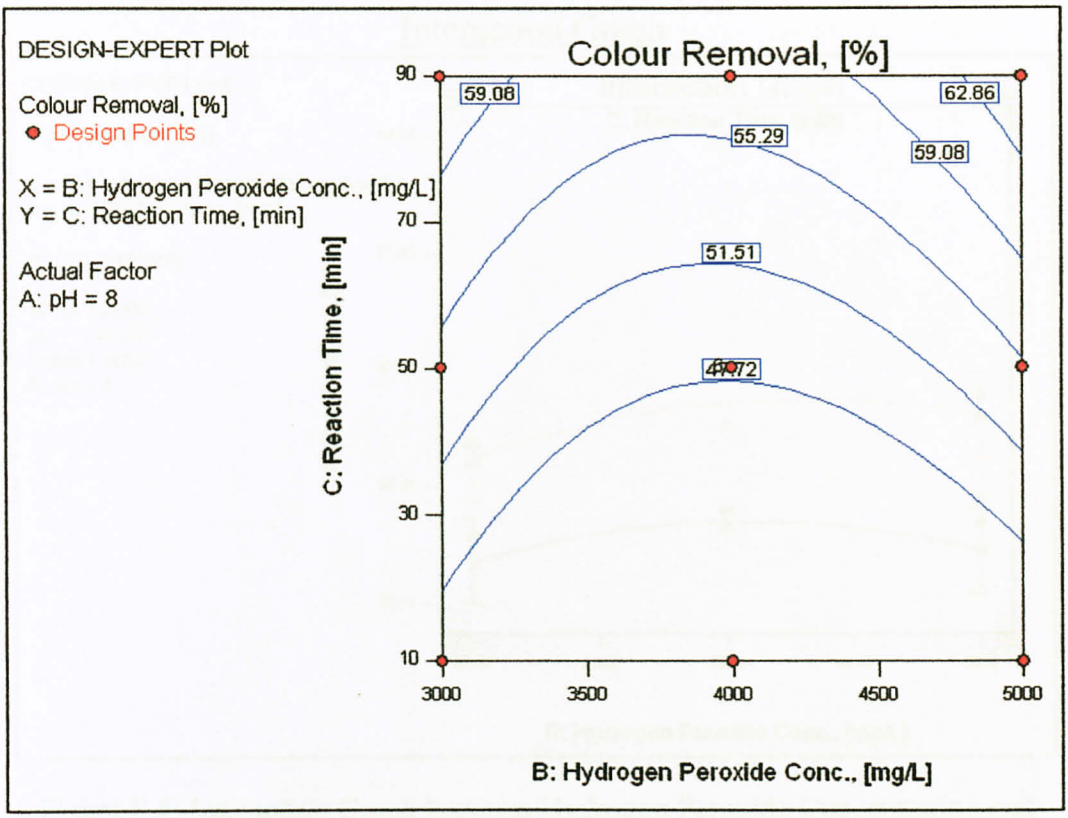

Figure F.3: Contour Plot of Colour Removal at pH 8

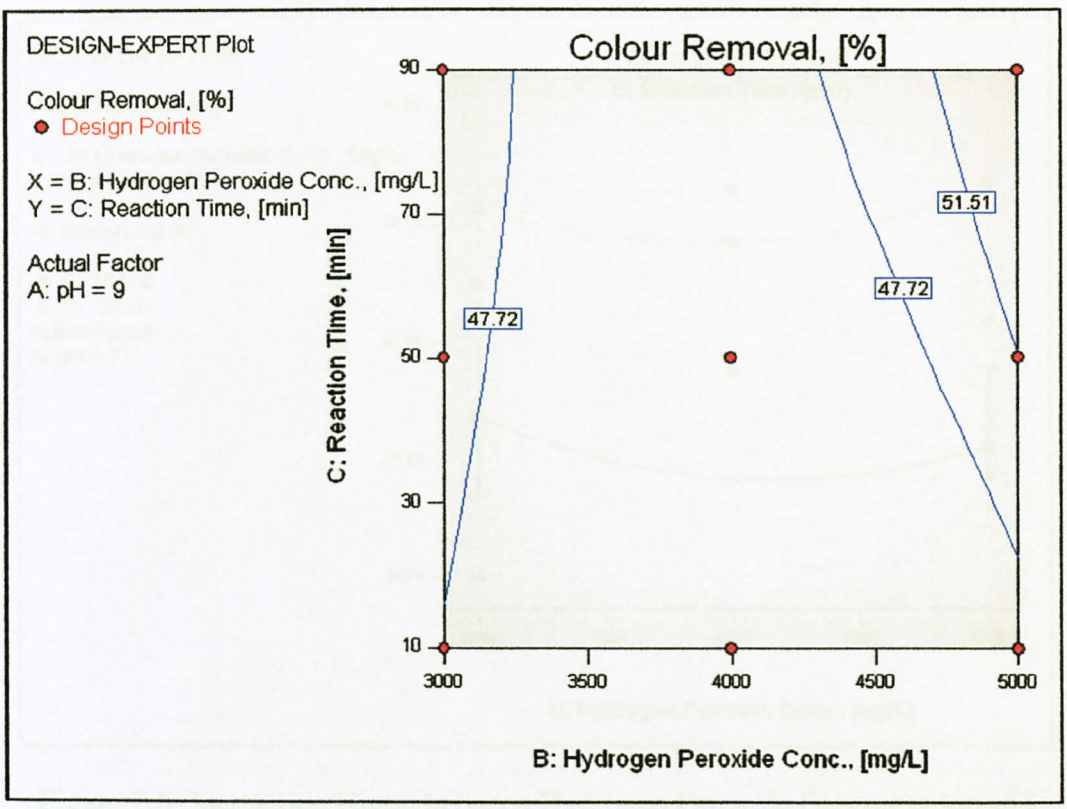

Figure F.4: Contour Plot of Colour Removal at pH 9

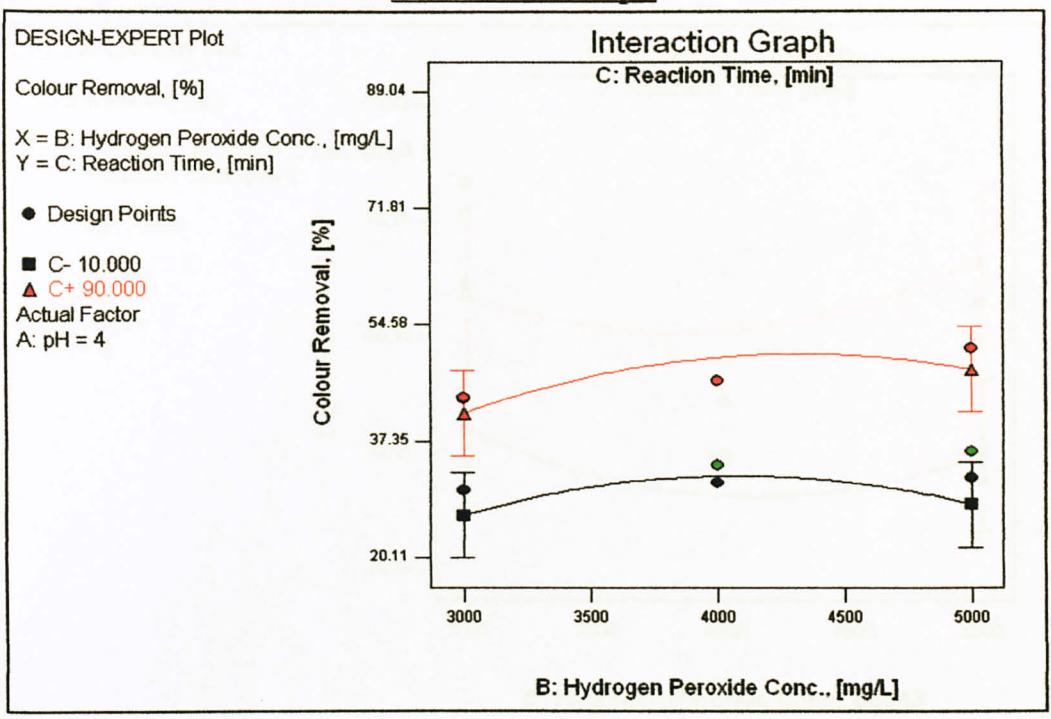

Figure F.5: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on Colour Removal at pH 4

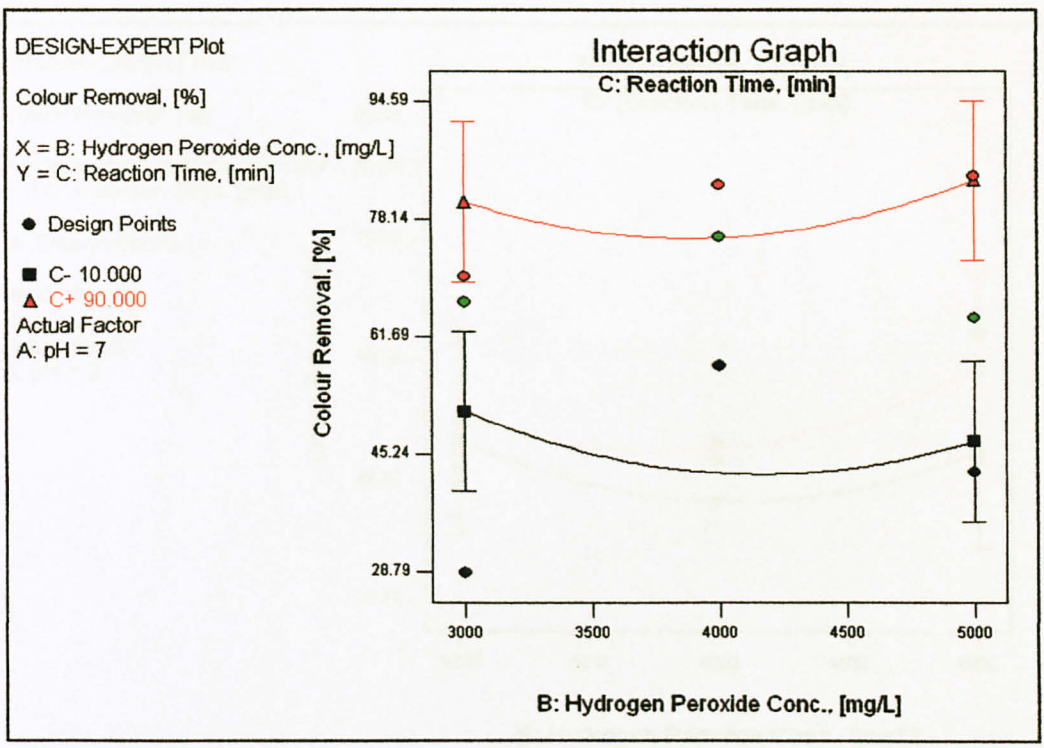

Figure F.6: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on Colour Removal at pH 7

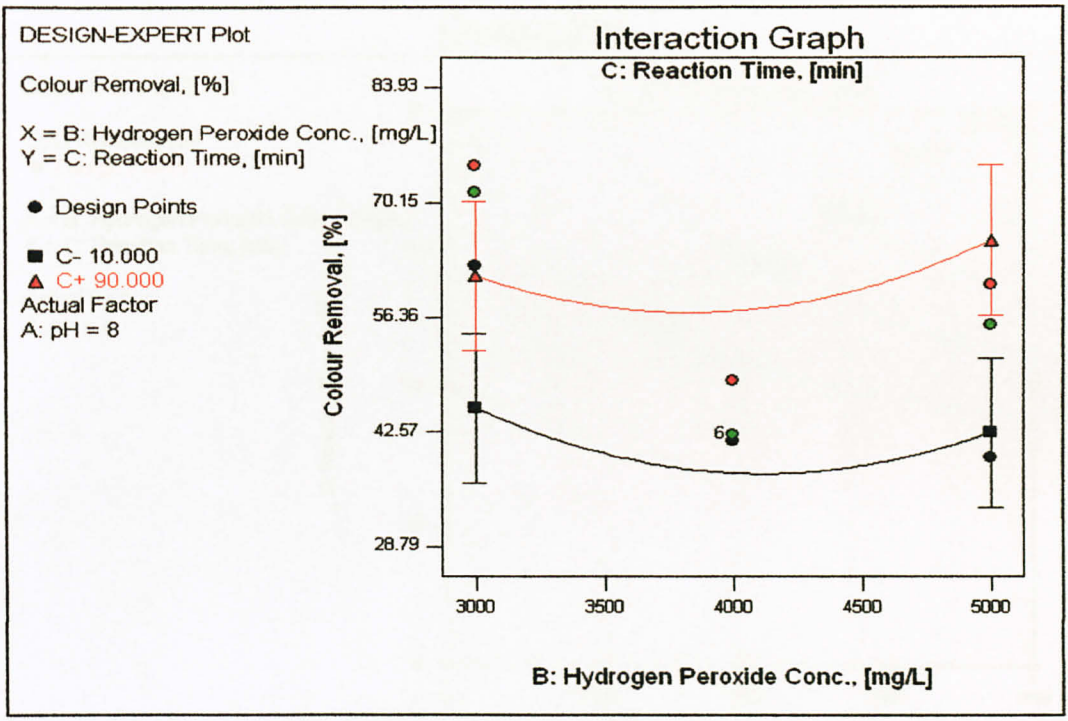

Figure F.7: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on Colour Removal at pH 8

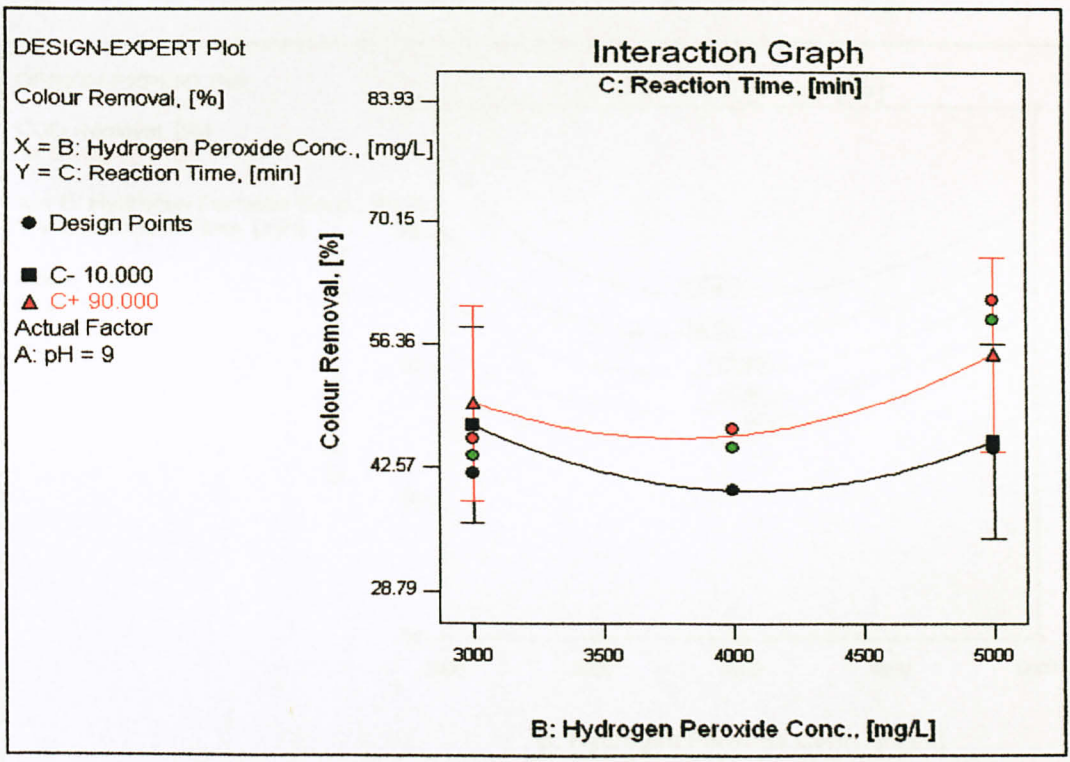

Figure F.8: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on Colour Removal at pH 9

Response: Chemical Oxygen Demand Removal

Contour Plot

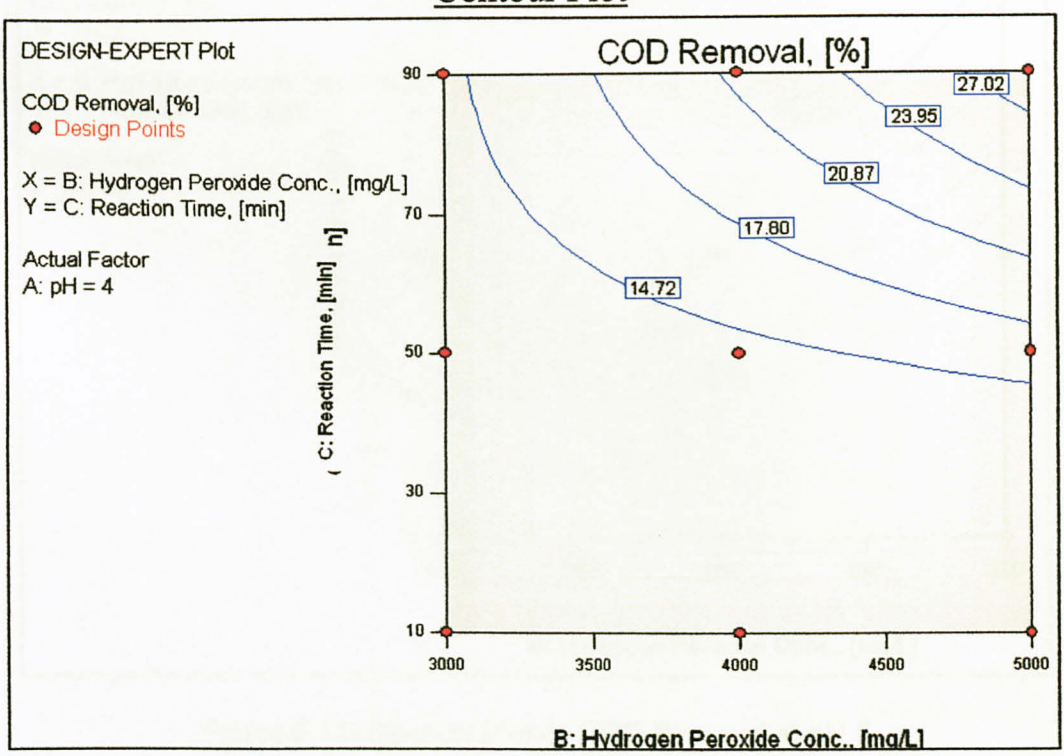

Figure F.9: Contour Plot of COD Removal at pH 4

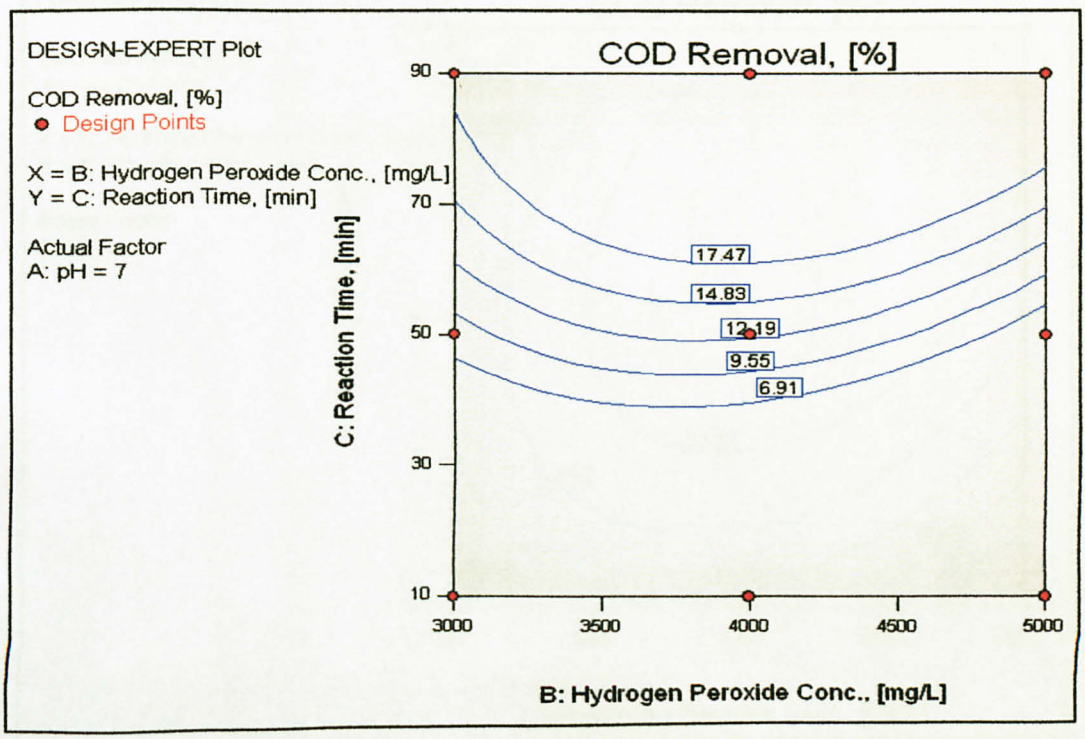

Figure F.10: Contour Plot of COD Removal at pH 7

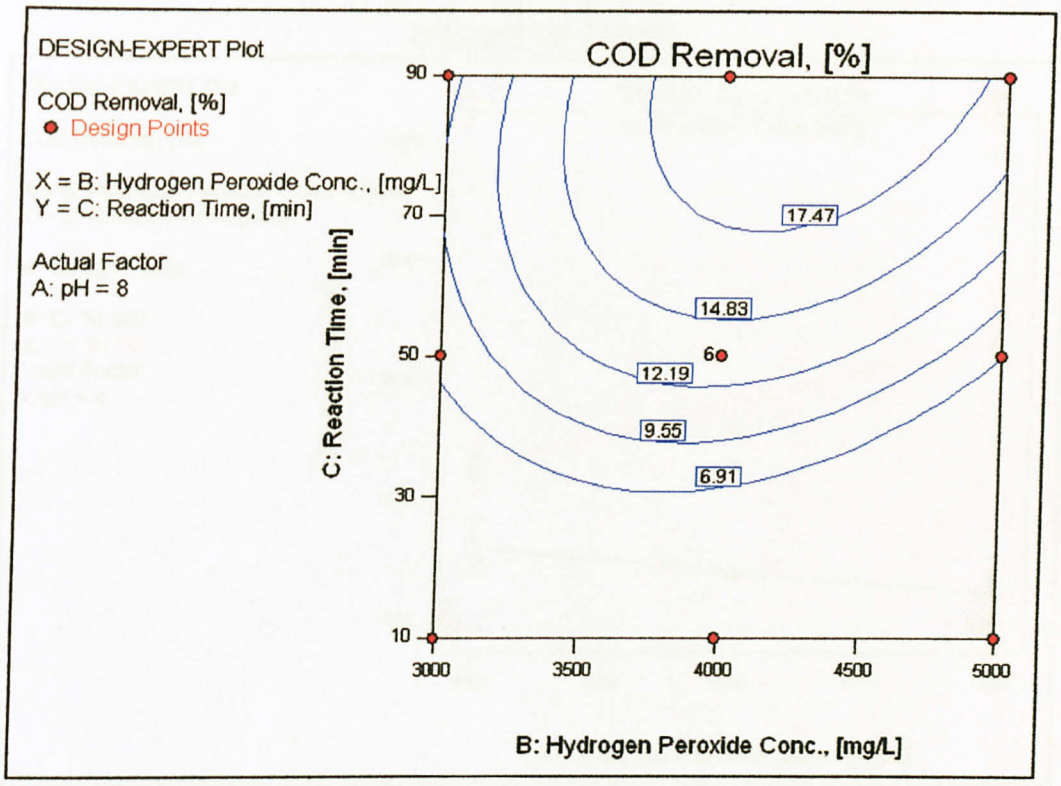

Figure F.11: Contour Plot of COD Removal at pH 8

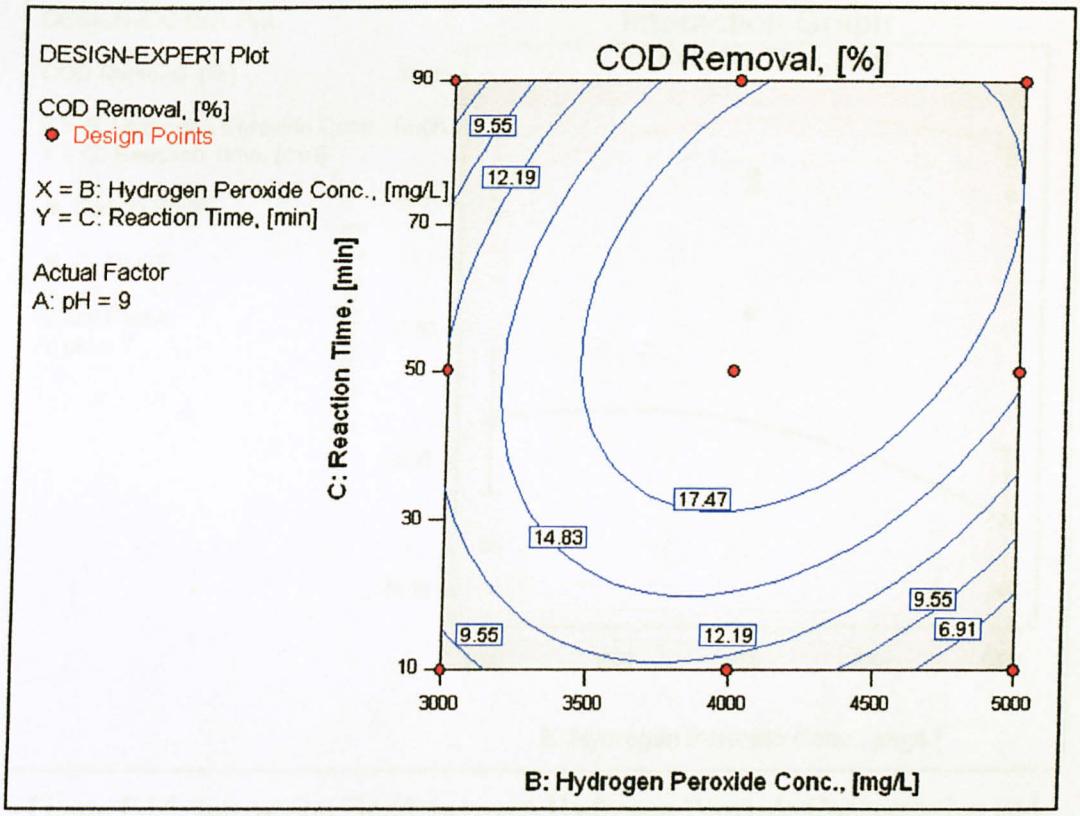

Figure F.12: Contour Plot of COD Removal at pH 9

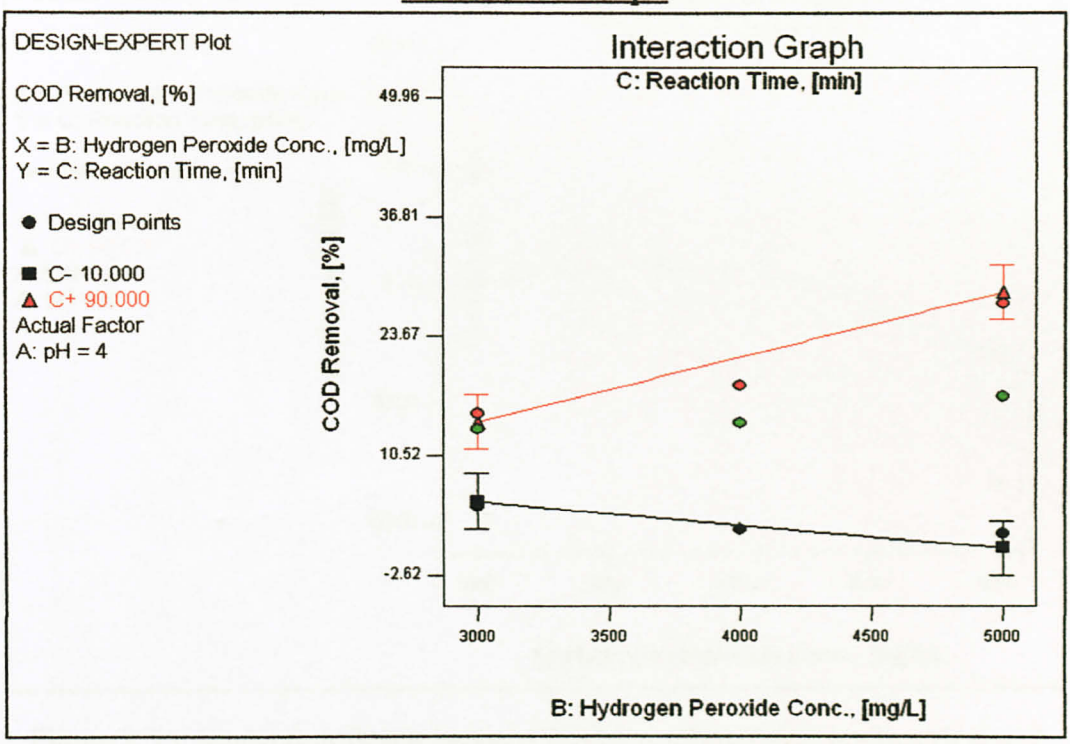

Figure F.13: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on COD Removal at pH 4

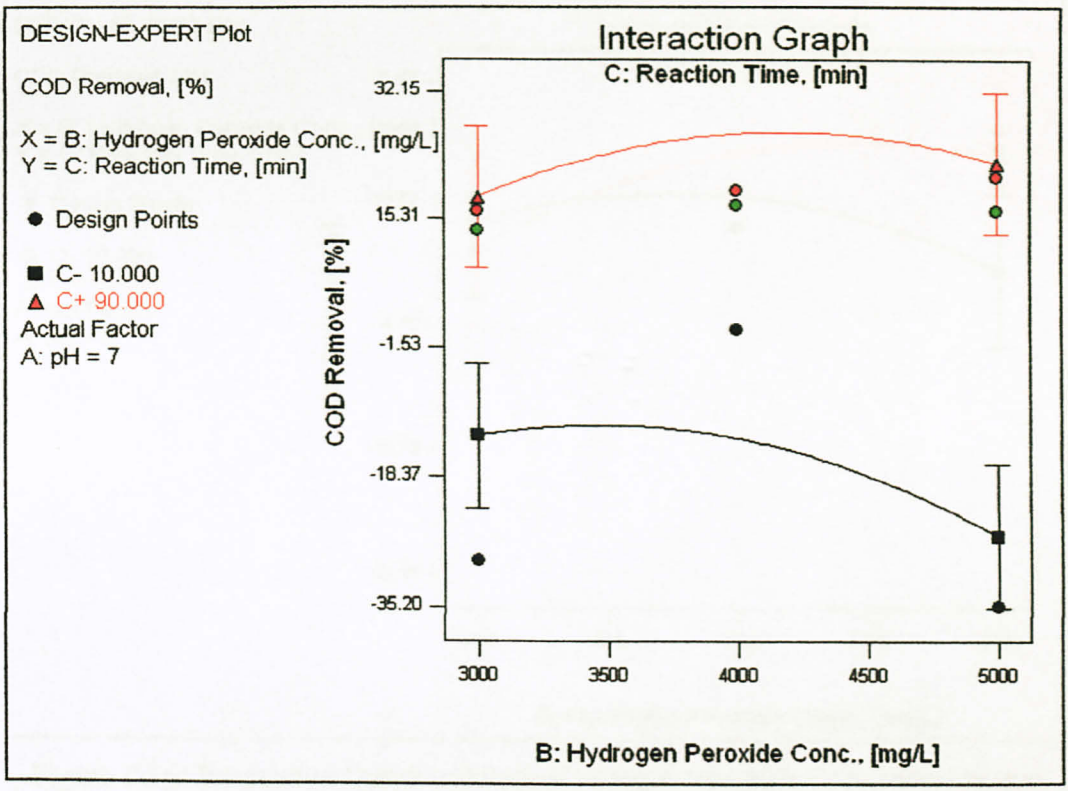

Figure F.14: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on COD Removal at pH 7

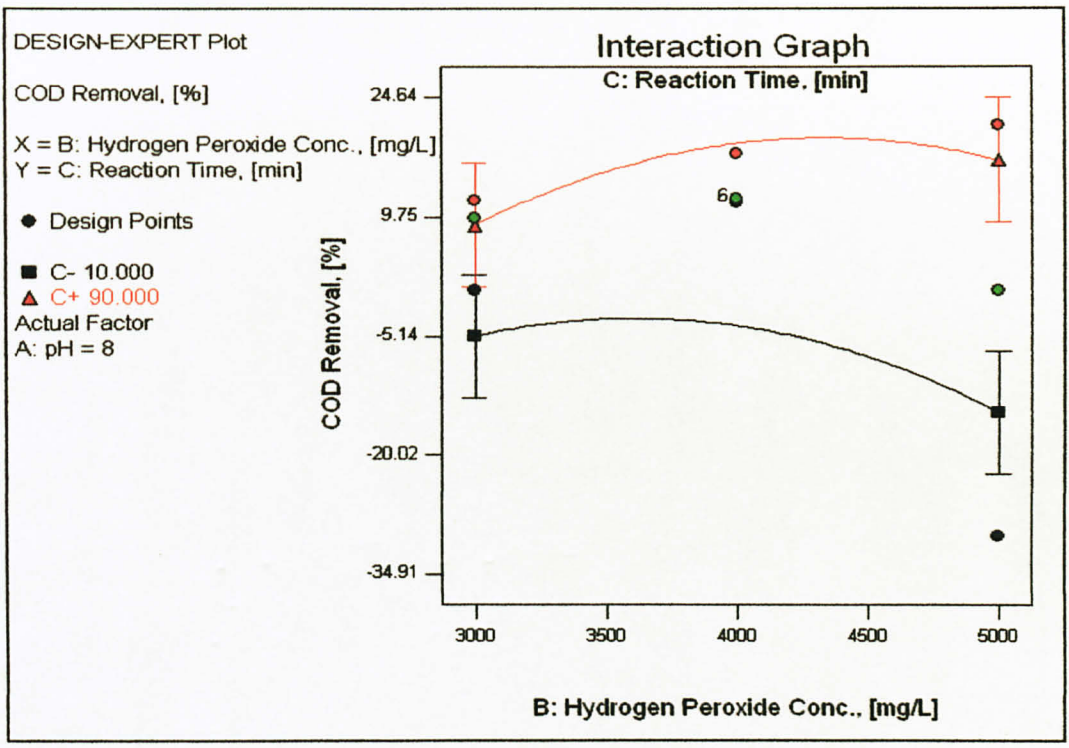

Figure F.15: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on COD Removal at pH 8

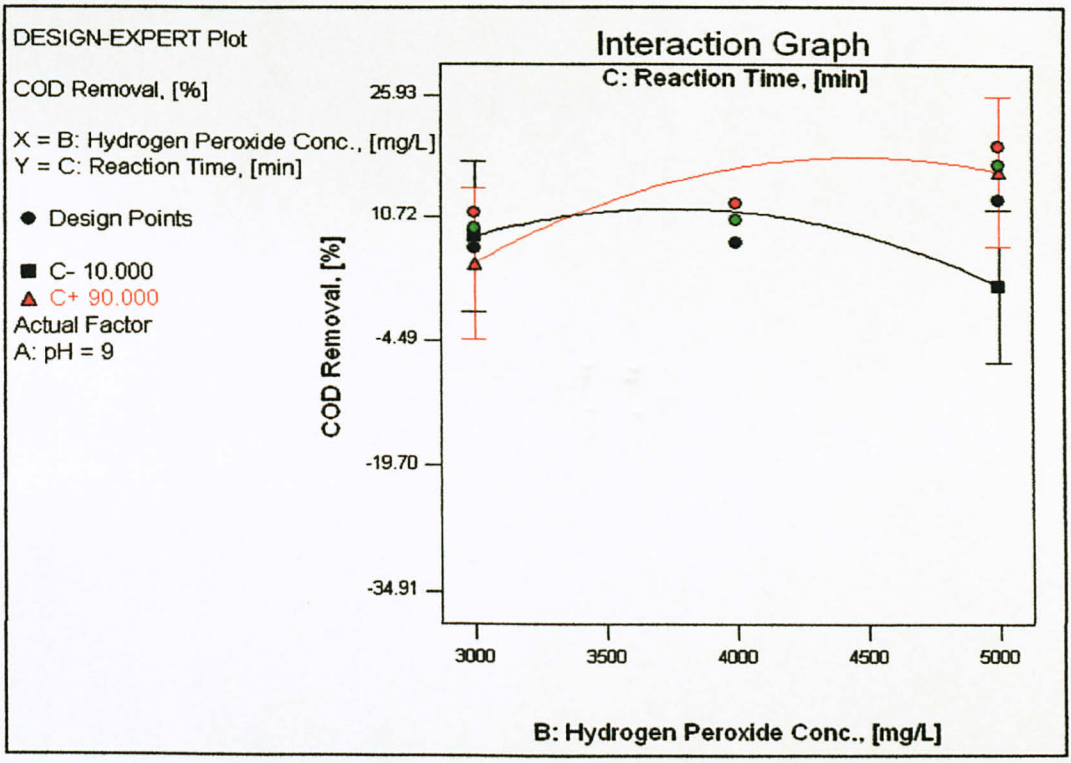

Figure F.16: Interaction Graph between Hydrogen Peroxide Concentration and Reaction Time on COD Removal at pH 9